### A Distributed Optical Telescope: Principle and Expected Performance

Sébastien Leprince

California Institute of Technology, USA

March 30, 2010 Keck Institute for Space Studies Workshop

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <



### People Involved during Study Period

#### **Techniques:**

- Renaud Binet (stereo imagery),
- Francois Ayoub (COSI-Corr development),
- Lionel Keene (fast computing),
- Remi Michel (optics),
- Neus Sabater (correlation),
- Sergio Pellegrino (micro satellite design).

#### **Applications:**

- James Hollingsworth (tectonics),
- Jean-Philippe Avouac (tectonics),
- Bodo Bookhagen (geomorphology/glaciology),
- Mike Lamb and students (geomorphology),
- Pieter Vermeesh (geomorphology),
- Etienne Berthier (glaciology).

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

## Generally Identified Imagery Needs in Earth Sciences from Last Workshop:

Global coverage,

- High temporal sampling,
- Old archives to create long time series,
- Large, medium , and high spatial resolutions,

**To study and monitor:** ground deformation and evolution of Earth's topography (relation to earthquakes, landslides, mountainous glaciers, sand dunes), evolution of vegetation, river channels, coastal areas, ice caps, etc...

## Coverage of Current Sun-synchronous Optical Satellites

All Sun-synchronous satellites on elliptical orbit with inclination between  $96^{\circ}$  and  $100^{\circ}$ , leading to an **Earth coverage between**  $\pm$ **81-84** $^{\circ}$  **latitude**.

- ► Landsat: (LS1-3) Inclination of 99.2°, (LS 4-7) Inclination of 98.2°
- SPOT 1-5 satellites: Inclination of 98.7°
- ASTER on-board NASA Terra: Inclination of 98.5°
- IRS: Inclination of 98.7°
- Quickbird, Worldview-1, Worldview-2: Inclinations of 98°, 97.2°, 97.8°

- Formosat 2: Inclination of 99.14°
- Pleiades-HR: Inclination of 98.2°

## Coverage of Current Sun-synchronous Optical Satellites: Landsat example ( $\pm 82^{\circ}$ latitude)



Credit: http://www.planetobserver.com/

Coverage of Current Sun-synchronous Optical Satellites: Landsat example ( $\pm 82^{\circ}$  latitude)



Credit: Google Earth

・ロト・日本・日本・日本・日本・日本・日本

# Temporal Sampling Combining Existing Optical Satellites: How many satellites on orbit?

ESTIMATED # OF OPTICAL SATELLITES ON ORBIT



Number of land observing satellites with ground resolution better than 60 m.

Document current as of the end of 2007. Accurate from 2007-2012.

Consider that there exists, on average, 40 optical land imaging satellites on orbit.

From "ASPRS Guide to Land Imaging Satellites", W.E. Stoney, Feb. 2008

▲ロト ▲ □ ト ▲ □ ト ▲ □ ト ● ● の Q ()

Two different scenarios:

- Tasking: Observing satellites have either a large swath or depointing capabilities for global coverage. Typically acquire images of a specific area within less than 1 week of a specific request. Current average of 5.7 images/day. Since satellites are all Sun-synchronous on descending nodes between 8:30 11:30 am, we could achieve temporal sampling of a particular area with opportunistic maximum average of 30 min, during at most a few days. This scenario usually happens after large crises, e.g., Haiti earthquake (Disaster International Charter).
- Archive mining: Average long-term revisit time of a particular area is highly variable, between 2 weeks to 1 year, and depends on swath width, orbital period, downlink capabilities, etc... For instance...

Two different scenarios:

- Tasking: Observing satellites have either a large swath or depointing capabilities for global coverage. Typically acquire images of a specific area within less than 1 week of a specific request. Current average of 5.7 images/day. Since satellites are all Sun-synchronous on descending nodes between 8:30 11:30 am, we could achieve temporal sampling of a particular area with opportunistic maximum average of 30 min, during at most a few days. This scenario usually happens after large crises, e.g., Haiti earthquake (Disaster International Charter).
- Archive mining: Average long-term revisit time of a particular area is highly variable, between 2 weeks to 1 year, and depends on swath width, orbital period, downlink capabilities, etc... For instance...

- ASTER, 15 m GSD on-board Terra: 705 km altitude, 99 min orbital period, 233 orbits and 16-day repeat cycle. For complete coverage the swath should be 172 km wide, but it is only 60 km. Slowly drifting orbit that achieves complete coverage in about three cycles. Every point on Earth is covered at least once every 43 days by the ASTER instrument.
- Quickbird, 60 cm GSD: 450 km altitude, 307 orbits and 20-day repeat cycle, 16.5 km swath. Needs eight cycles to achieve global coverage. Every point on Earth is covered every about 160 days by Quickbird.
- **Landsat 7, 15-60 m GSD:** same orbit as Terra, swath of 185 km, Landsat revisit time is 16 days.
- SPOT 1-5, 10-2.5 m GSD: 2×60 km swath, 832 km altitude, 363 orbits and 26-day repeat cycle, repeat coverage of 26 days using both instruments, or 52 days with one instrument.

- ASTER, 15 m GSD on-board Terra: 705 km altitude, 99 min orbital period, 233 orbits and 16-day repeat cycle. For complete coverage the swath should be 172 km wide, but it is only 60 km. Slowly drifting orbit that achieves complete coverage in about three cycles. Every point on Earth is covered at least once every 43 days by the ASTER instrument.
- Quickbird, 60 cm GSD: 450 km altitude, 307 orbits and 20-day repeat cycle, 16.5 km swath. Needs eight cycles to achieve global coverage. Every point on Earth is covered every about 160 days by Quickbird.
- **Landsat 7, 15-60 m GSD:** same orbit as Terra, swath of 185 km, Landsat revisit time is 16 days.
- SPOT 1-5, 10-2.5 m GSD: 2×60 km swath, 832 km altitude, 363 orbits and 26-day repeat cycle, repeat coverage of 26 days using both instruments, or 52 days with one instrument.

- ASTER, 15 m GSD on-board Terra: 705 km altitude, 99 min orbital period, 233 orbits and 16-day repeat cycle. For complete coverage the swath should be 172 km wide, but it is only 60 km. Slowly drifting orbit that achieves complete coverage in about three cycles. Every point on Earth is covered at least once every 43 days by the ASTER instrument.
- Quickbird, 60 cm GSD: 450 km altitude, 307 orbits and 20-day repeat cycle, 16.5 km swath. Needs eight cycles to achieve global coverage. Every point on Earth is covered every about 160 days by Quickbird.
- Landsat 7, 15-60 m GSD: same orbit as Terra, swath of 185 km, Landsat revisit time is 16 days.
- SPOT 1-5, 10-2.5 m GSD: 2×60 km swath, 832 km altitude, 363 orbits and 26-day repeat cycle, repeat coverage of 26 days using both instruments, or 52 days with one instrument.

- ASTER, 15 m GSD on-board Terra: 705 km altitude, 99 min orbital period, 233 orbits and 16-day repeat cycle. For complete coverage the swath should be 172 km wide, but it is only 60 km. Slowly drifting orbit that achieves complete coverage in about three cycles. Every point on Earth is covered at least once every 43 days by the ASTER instrument.
- Quickbird, 60 cm GSD: 450 km altitude, 307 orbits and 20-day repeat cycle, 16.5 km swath. Needs eight cycles to achieve global coverage. Every point on Earth is covered every about 160 days by Quickbird.
- Landsat 7, 15-60 m GSD: same orbit as Terra, swath of 185 km, Landsat revisit time is 16 days.
- SPOT 1-5, 10-2.5 m GSD: 2×60 km swath, 832 km altitude, 363 orbits and 26-day repeat cycle, repeat coverage of 26 days using both instruments, or 52 days with one instrument.

## Only from the Landsat, ASTER, SPOT, and Quickbird systems, we should expect every point on Earth to be revisited at least once every 6 days.

In practice, satellite availability and cloud cover decrease this estimate. If we consider only 30% probability of clear sky ([Miller et al., 2007] using MODIS), we can expect an average revisit time of about 22 days.

#### Creating Long Time Series: How far back does the archive goes?

OPTICAL LAND IMAGING SATELLITES WITH 56 METERS OR BETTER RESOLUTION

Addit_IT         COUNTRY         LAURCH         PARKES.M         SMD RES.M         SMD R			BT LAUNCH I	DATE		
Landard 5         US         D.0144         D.0         HB           Not 10         Frade         D.0147         HB         D.0         HB           Not 20         Frade         D.0147         HB         HB         D.0         D.0147           Not 20         Frade         D.0209         4.8         D.0         D.0         HB           NOT 20         Frade         D.0209         4.8         D.0         D.0         HB           NOT 20         Frade         D.0209         4.8         D.0         D.0         HB         D.0         D	SATELLITE	COUNTRY	LAUNCH	PAN RES. M	MS RES. M	SWATH KM
SPOT3         Prace         012390         10.3         20         12.9           RFD 1         16.3         00.2097         6.0         11390         11400           SPOT3         Prace         002498         10.3         120         11400           SPOT4         10.3         10.3         120         11400         11400           SPOT3         Prace         002498         10.3         120         10.4           SPOT3         10.4         01.5         10.4         11         11.5         10.4         11           SPOT3         10.4         10.5         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4         11         10.4 <td>Landsat 5</td> <td>US</td> <td>03/01/84</td> <td></td> <td>30.0</td> <td>185</td>	Landsat 5	US	03/01/84		30.0	185
Dis 10         India         Description         E2         PA         Feb           Proba         E3.44         102107         11         11         10         14         10         <	SPOT-2	France	01/22/90	10.0	20	120
meas         is 3A         tiz (207)         max         11 Hpg         H. 4           SUD1247         FU26         0226         10         25         109           SUD1247         FU26         0226         10         25         109           SUD1247         FU26         0226         10         4         11           SUD1247         FU26         0226         10         4         11           SUD1247         FU26         0226         4.6         15         5.9         9           SUD1247         FU26         5         100         5         9         7           SUD1247         FU26         6.6         5         5         9         7           SUD1247         FU26         6.6         5         2         10         7           SUD251611(ST1)         FU26         6.6         2.8         12         12         6           SUD251611(ST1)         Nuckey         62764         2.8         2         12         6           SUD25161(ST1)         Nuckey         62764         2.8         2         12         6           SUD2517(ST1)         SUD4         627664         2.8	100.40	India	00/20/07	6.0	22	70.442
CHOPT         Paska         D22 (207)         10 3         H 207	ina in	india	00/20/07	0.0	2.3	10, 142
Dirt         Product         P	Proba	ESA	10/21/97		18 Hyp	14
Landar 7 Landar	SPOT-4	France	03/24/98	10.0	20	120
MCAUCE-3         US US         B02.499         L.3         L.4         e.9         11           MCAUCE-3         Koras         TC2009         4.8         15         17           CDA         MCAUCE-3         TC2009         4.8         17         17           CDA         MCAUCE-3         TC2009         4.8         17         17           CDA         MCAUCE-3         TC2009         4.8         18         17           CDA         MCAUCE-3         TC2009         4.8         2.3         12         160           CAUCEARD-12         MCAUCE-3         TC20         2.3         12         2.6         2.3         12.0         2.6         2.3         2.2         6.0         6.0         2.0         2.0         2.0         2.0         6.0         0.0         10.0         10.0         0.	Landsat 7	US	04/15/99	15.0	30	185
THERAL AUTER)         Japan-NUE         121199         15         5.0         9         60           DEAT         102         112109         10         30         37           EGDA A         Aural         120505         1.0         30         40           OMC Affatt (1871)         Algenta         102402         20         600         20         600           DME Coll (1871)         Mayeria         6027(103         2.0         6         2.2         600           DME Coll (1871)         Mayeria         6027(103         2.0         6         2.0         10         10           DME Coll (1871)         Mayeria         6027(60         2.0         2.0         10	IKONOS-2	US	09/24/99	1.0	4	11
KOMPART         Extra 1         12/2099         6.8         17           Gardamird 2         US         16/16         30         14           Gardamird 2         US         16/16         15/10         15/10           Obt Call (STL)         Tarkey         06/2703         12.0         24         34, 22           Obt Call (STL)         Tarkey         06/2703         12.0         2         2         600           Obt Call (STL)         Null 10         06/7703         2         2         600         14           Obt Call (STL)         Null 10         06/7703         2         0         14         16           RE Cancual 1         Holis         10/1703         4         2.0         3         14           RE Cancual 1         Holis         10/1703         4         2.0         15         14           RE Cancual 1         Holis         10/17070         2.0         1         1         1         1	TERRA (ASTER)	Japan/US	12/15/99		15, 30, 90	60
EG1         US         11/21/800         16/3         30         31           Displantiz         ///2         10/200         1.5         2.5         1.6           Displantiz         ///2         10/200         1.5         2.5         1.6           Displantiz         //2         10/200         1.2         1.6         1.7           Displantiz         //2         0.0         1.7         1.7         1.7           Displantiz         //2         0.0         1.7         1.2         2.5         1.6           Displantiz         Market         0.0         0.0         2.5         2.6         2.6           Displantiz         Market         0.0         0.0         2.2         0.0         1.7           Displantiz         Market         0.0         0.0         0.0         0.0         1.7           Displantiz         Market         0.0         0.0         0.0         0.0         1.7         0.0         1.1           Displantiz         Market         0.0         0.0         0.0         0.0         1.1         0.0         0.0         1.1         0.0         0.0         1.1         0.0         0.0         1.1	KOMPSAT-1	Korea	12/20/99	6.6		17
ENDS A1         Aradi         100500         1.3         m         4           Constitution         U.G. SCH104         0.6         1.3         1.4         44           Constitution         U.G. SCH104         0.6         1.3         1.4         46           Constitution         U.G. SCH104         0.6         1.3         1.4         46           Constitution         Transverse         2.3         1.60         2.5         4.6           Constitution         Transverse         0.807/03         1.2         2.5         3.6         4.6           DMC UK (ST1)         Transverse         0.907/03         2.0         0.7         2.4         1.4         1.0           DMC UK (ST1)         Transverse         0.4006         2.0         8         2.4         1.0         1.4         1.0         1.0         1.4         1.0         1.0         1.4         1.0         1.0         1.4         1.0         1.0         1.4         1.0         1.0         1.4         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         1.0         <	E0.1	110	11/21/00	10.0	20	37
Darkshmin2         P/2         Ver(16)         9.8         2.8         16           Darkshmin2         PP1-7         Pinace         00.4024         2.4         10         128           SP1-7         Pinace         00.4022         2.4         10         128         128           DVC Edits         Pinace         00.4022         2.4         10         128         24         129           DVC Edits         Pinace         00.70703         12.8         2.2         660         00           DVC Edits         Pinace         00.70703         2.3         660         00         10         00         00.401	EDOT AL	00	10121/00	10.0		
Data Net         Disk         State         Disk	ERUSAT	157301	12/05/00	1.0		19
APD 14.         Praces         B00 4692         2.3         10         100           APD 15.         Yestery         602 4692         2.3         10         100           APD 15.         Yestery         602 7783         12.0         25         54.12           APD 15.         Nick W         602 7783         12.0         25         54.12           DMC 16 March 101         Nick W         602 7783         12.0         23         660           Mick Resources APD         Taken         642 6647         2.8         2         1.4           Resources APD         Taken         642 6647         2.8         2         1.4           Resources APD         Taken         642 6647         2.8         2         660           Resources APD         Taken         642 6647         2.8         2         660           Resources APD         Taken         642 664         2.8         2         660           Resources APD         Taken         642 664         2.8         1.6         1.6           Resources APD         Taken         642 664         1.8         1.6         1.6           Resources APD         Takened         642 664         1.8         <	QuickBird-2	US	10/18/01	0.6	2.5	16
Other Addish (19871)         Algoria         11/28/23         12         600           Other Addish (19871)         Name 16         00/27/33         12         600           Other Current Soft (1871)         Name 16         00/27/33         12         600           Other Current Soft (1871)         Name 16         00/27/33         12         600           Other Current Soft (1871)         Name 16         00/27/33         12         600           Other Current Soft (1871)         Name 16         00/27/33         12         600           Other Current Soft (1871)         Name 16         00/27/33         20         20         111           Other Current Soft (1871)         Name 16         02/02/02         2.0         2.0         2.0         113           Other Current Soft (1871)         Name 16         02/02/02         2.0         10         3.7         1           Northoff (1471)         Name 16         02/02/02         2.0         10         3.7         1           Northoff (1471)         Name 16         02/02/02         2.0         10         3.7         1           Northoff (1471)         Name 16         02/02/02         2.5         5         1         3.7         1     <	SPOT-5	France	05/04/02	2.5	10	120
DMC District (STL)         Turkey         062783         12.0         24         34, 42           DMC District (STL)         Nu <sup>10</sup> 067783         2.0         34, 62         34, 62           NIR Resourcestain         India         101/793         6.0         6, 22, 56         74, 40, 60           NIR Resourcestain         India         101/793         6.0         6, 22, 56         74, 40, 60           NIR Construct         India         101/793         6.0         74, 40, 60         34, 40           NIR Construct         India         050460         2.0         74, 40, 60         36, 60           NIR Construct         India         101/793         6.0         22, 5         60, 60           NIR Construct         India         101/793         2, 0         5         10, 15           NIR Construct         102/793         2, 0         5         10, 15         7           NIR Construct         102/793         2, 0         5         10, 15         7           NIR Construct         India         101/797         2, 0         3         2         10           NIR Construct         India         101/197         0, 0         2         15         7, 2 <t< td=""><td>DMC AlSat-1 (SSTL)</td><td>Algeria</td><td>11/28/02</td><td></td><td>32</td><td>600</td></t<>	DMC AlSat-1 (SSTL)	Algeria	11/28/02		32	600
Disk Visioniskis-f (SSTL)         Nigeria         Disk 7         Disk 7 <thdisk 7<="" th=""></thdisk>	DMC BilSat (SSTL)	Turkey	09/27/03	12.0	26	24.52
Disk C UK (1871)         Disk D UK (1871) <thdisk (1871)<="" d="" th="" uk=""> <thdisk (1871)<="" d="" t<="" td="" uk=""><td>DMC NiceriaSat-1 (SSTL)</td><td>Nigeria</td><td>09/27/03</td><td></td><td>32</td><td>600</td></thdisk></thdisk>	DMC NiceriaSat-1 (SSTL)	Nigeria	09/27/03		32	600
Intel Resourcesse:         Intel Account of Status         1017/03         2.0         6,22,3         6,22,3         6,22,3         2,23         113           INS Control 1         Rola 0         60465         2.0         2.0         113           INS Control 1         Rola 0         60465         2.0         2.0         113           INS Control 1         Rola 0         604665         2.0         2.0         3.0           INS Control 1         Rola 0         604665         2.0         2.0         3.0           INS Control 1         Loc 10         1.0         3.0         3.0         3.0         3.0           TopExt (ST1)         Lik         1.0         1.0         3.0	DMC LIK (SSTL)	LIK	09/27/03		32	600
ChessBirgs         102/103         20.0         10.0         10.0         10.0           ChessBirgs         Tarawa         47.00         20.0         8         24           ChessBirgs         Tarawa         47.00         20.0         8         24           MOMTORICAT         Tarawa         67.00         20.0         10.0         10.70           ALGS         Momtoria         67.00         67.0         20.0         10.0         10.0           ALGS         Momtoria         67.00         67.0         20.0         10.0         10.0           ALGS         Momtoria         67.00         60.0         10.0         10.0         10.0           REGE         Momtoria         67.00         60.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0         10.0	DING OK (BATL)		09/27/03		0 00 50	000
Diblock of 2         Diblock of 2<	IRS Resourcesat-1	india	10/17/03	6.0	6, 23, 56	24, 140,740
CDBMCAR3         Tatural         04/204         2.0         8         24           CDBMCAR3         Tatural         04/204         2.0         8         24           Manage 110         Kasata         06/204         2.0         20         9         4.4           Manage 110         Casata         06/204         2.0         20         9         4.4           Manage 110         Casata         06/204         2.3         10         10         5           Manage 110         Casata         06/204         2.3         10         3         7           Manage 110         Facata         06/204         2.3         10         3         7           Resum 10         Facata         06/1607         2.0         2         10         3         7           Resum 10         Facata         06/1607         2.0         2         7	CBERS-2	China/Brazil	10/21/03	20.0	20	113
Rid Gernari I. India 603469 2.2 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	FORMOSAT-2	Taiwan	04/20/04	2.0	8	24
MONTIOR: 1.1         Russis         Decision         12.0         94.180           MONTIOR: 1.1         Life         607269         8.2         20         94.180           MADE         Japan         012408         2.3         10         35.10           ALGS         Japan         012408         2.3         10         35.10           MADE         Mark         012408         2.3         10         35.10           MADE         Prizzos         1.3         3         72           ROMPART2         Korea         072208         1.3         3         72           ROMPART2         Korea         072208         1.3         4         15           ROMPART2         Korea         072208         1.3         4         15           ROMPART2         Charatitrazt         041097         2.0         2.0         10         10           ROMPART2         Charatitrazt         041097         2.0         2.0         10         7           ROMPART2         Charatitrazt         041097         2.0         2.0         10         10           ROMPART2         Charatitrazt         041097         2.0         2.0         10         <	IRS Cartosat 1	India	05/04/05	2.5		30
Beding-Class         China         1927/95         2.4         122         607           Dirola (SST.)         US         907/95         2.5         10         15,19           Dirola (SST.)         US         907/95         2.5         10         15,19           EROS 81         Areal         442/56         6.7         9         1,19           EROS 81         Areal         642/56         10         4         43           Moreal         07/207         5.8         4         43           Micro 807/207         0.8         4         43         44           Micro 807/207         0.8         4         43         45           Micro 807/207         0.8         4         43         45           Micro 807/207         0.8         5         20         113           TitleSC means 1         The limit 4         607/97         5.8         10         77           TitleSC means 2         Chark 840/97         2.9         10         72         72         5.9         77           TitleSC means 2         Chark 840/97         0.00         2.5         10         77         7         7         7           Read	MONITOR-E -1	Russia	08/26/05	8.0	20	94, 160
Top-Sate (SP11)         UK         1627/95         2.5         8         4.5         15           ALGS #         Jamel B12466         2.5         10         3.7         7           Resur DC (E145)         Kasata         661/565         1.3         3         7           WorldYow 1         G5         61/57         0.5         14         15           Resurt DC (E145)         Chasata         60/1697         0.5         15         12,40           Resurt DC (E145)         Chasata         60/1697         0.5         15         12,40           Result PA         Chasata         60/1697         0.5         15         12,40           Result PA         Chasata         60/1697         0.5         15         12,40           Result PA         Chasata         60/169         5         16         7           Result PA         Chasata         60/169         5 <t< td=""><td>Belling-1 (SSTL)</td><td>China</td><td>10/27/05</td><td>4.0</td><td>32</td><td>600</td></t<>	Belling-1 (SSTL)	China	10/27/05	4.0	32	600
ALCO         Jassin         072409         2.2         10         13, 10           ALCO         Jassin         072409         2.1         13, 10         7           REOS B1         Marael         44.206         0.7         7         7           NOMPALY 110         Moral         072409         1.0         4         13           NOMPALY 121         Molit         0110077         0.3         0         10         1           NOMPALY 121         Molit         0110077         0.4         3         10         10           NOMPALY 121         Molit         0110077         0.4         3         10         10           NOMPALY 121         Molit         0110077         0.2         2.0         10         10           Cheskings         Tealing         021778         2.5         10         1.7         10           Cheskings         Tealing         021778         2.5         10         10         7           Li-1.4         Cheskings         Tealing         02169         4.5         7         7           Li-1.4         Cheskings         Cheskings         10         10         2.5         10         7	TonSat (SSTI)	116	10/27/05	2.5		10.15
nt.co en la construction de la c	ALOF	UK Internet	01/24/05	2.0		36,70
Introls min         Introls min         Introls min         Introls min         T           Normal 1         Korea         07,809         1.0         1         7           Normal 1         Korea         07,809         1.0         4         4           Normal 1         Korea         07,809         1.0         4         4           Normal 1         Korea         07,809         2.0         20         10           RESC2         Charatizat         04,809         2.0         20         10         7           Resca         Charatizat         04,809         2.0         10         17,7         7,7 <td>ALUS</td> <td>Japan</td> <td>01/24/06</td> <td>2.5</td> <td>10</td> <td>35,70</td>	ALUS	Japan	01/24/06	2.5	10	35,70
Result ACD         Result OP         Result ACD         Del 30         3         28           Mean AD         Units         Inits         10         3         28           Mark AD         Units         Inits         0.10         3         28           Mean AD         Units         Ottors         0.10         3         28           Mean AD         Units         Ottors         0.10         3         2         10           Mean AD         Units         This         This         This         72.30         10         72.30           Mark AD         Data AD         Data AD         Data AD         0.0108         2.3         15         72.30           Mark AD         Data AD         Data AD         0.0108         2.3         17         72.30           Mark AD         Data AD         Data AD         0.0108         2.4         72.30         72.3           Mark AD         Data AD         Data AD         0.0108         2.5         16         78           Mark AD         Data AD         Data AD         0.0108         2.5         78         78           Mark AD         Data AD         DataDA         0.0108         2.5 <td>EROS B1</td> <td>Israel</td> <td>04/25/06</td> <td>0.7</td> <td></td> <td></td>	EROS B1	Israel	04/25/06	0.7		
Koteta         0728-95         1.0         4         15           KOMPAR/2         Koteta         0728-95         1.0         4         15           Koteta         01         05         011677         20.0         20         113           CREST21         Cheastbrazt         041967         20.0         20         113         16           CREST21         Cheastbrazt         041967         20.0         20         113         16           CREST21         Mayala         051069         2.0         5         7         7           Kul-LA         Cheastbrazt         640169         2.0         5         7         7           ReadBy-A         Cernery         640169         6.3         12         4         5           ReadBy-B         Gernery         640169         6.3         78         7	Resurs DK-1 (01-N5)	Russia	06/15/06	1.0	3	28
Hild         Outlog?         0.3         9.3         90           CREAS:10         Otherstand         Otherstand         0.1007         0.3         20         10           THOUS         Otherstand         Otherstand         0.1007         2.0         10         2.1         10           THOUS         Otherstand         0.0016         2.0         1.0         2.1         10         2.1         10         10           THOUS         Otherstand         0.0016         2.0         1.0	KOMPSAT-2	Korea	07/28/06	1.0	4	15
Weakform -1         1.63         Dent 697         9.5         14           Clines230         Clines240         25         5         7         13           ReadSaft         Clines         60.01         2.5         5         7         13           ReadSaft         Clines         60.01         2.5         5         7         7         13           ReadSaft         Clines         60.01         2.5         5.8         7         7         7           ReadSaft         Clines         60.01         2.5         5.8         7 <td>IRS Cartosat 2</td> <td>India</td> <td>01/10/07</td> <td>0.8</td> <td></td> <td>10</td>	IRS Cartosat 2	India	01/10/07	0.8		10
Characterization         Operating and provided and	WorldView 1	115	09/18/07	0.5		16
Theory         Data and the second secon	COEDE 20	China Brazil	09/10/07	20.0	20	10
Habitation         Displayed Barting         Displaye Barting         D	GBER0-2B	GinnarBrazii	09/19/07	20.0	20	113
Kathala         Bornania         Busines         2.3         3.5         10 Hop         725         50.0           Hui-1         China         6.0108         2.0108         3.5         10 Hop         725         50.0           Hui-1         China         6.0108         4.519         3.7         172         723         723           ReadBard         Gormeny         6.0108         6.5         78         723         723           ReadBard         Gormeny         6.0108         6.5         78	THOES	Thailand	02/27/08	2.0	15	22, 90
Li-L-A         China         Sch (16)         Sch (16)         TD, Sch (17)         TD, Sch (17)           Rightly-A         Germany         640168         5.0, 10, 17, 10         TP           Rightly-A         Germany         640168         6.3         TP           Rightly-A         Germany         640168         6.3         TP           Rightly-A         Germany         640168         6.3         TP           Rightly-B         Germany         640168         6.3         TP           Rightly-B         Germany         640168         6.3         TP           Rightly-B         Germany         640168         5.3         TP           Rightly-B         Germany         640168         5.3         TP           Wind New         Germany         640168         5.3         TP         TP           Wind New         Germany         640168         5.3         TP         TP         TP           Wind New         Germany         640168         5.3         TP         TP <td< td=""><td>RazakSat"</td><td>Malyasia</td><td>03/01/08</td><td>2.5</td><td>5</td><td>7</td></td<>	RazakSat"	Malyasia	03/01/08	2.5	5	7
Li-1-6         Chima         640198         10, 15, 300         720           Nucl-1-6         Germany         640198         10, 15, 300         720           Reading-1-6         Germany         640198         4.3         74           Reading-0         Germany         640198         2.4.5         10         57           K-dat         Stragecore         641698         2.4.5         10         57           K-dat         Stragecore         641698         2.4.5         10         57           Virus         Laraff Fance         660198         2.4         12         660           Virus         Laraff Fance         660198         5.0         5.2         460           Virus         Link         111568         7         2.4         740           DMC Linko-1         Link         111568         5.7         5.2         2.	HJ-1-A	China	04/01/08		30, 100 Hyp	720, 50
Readily-and         Germeny         64:01:99         5.3         78           Readily-and         Germeny         64:01:99         6.3         78           Readily-and         Germeny         64:01:99         6.3         78           Readily-and         Germeny         64:01:99         6.3         78           Readily-and         Germeny         64:01:99         7.3         7           Readily-and         Germeny         64:01:99         7.3         7           Markettilla-Statut Metera         64:01:99         7.3         7         7           Markettilla-Statut         Germeny         64:01:99         7.3         7         7           Markettilla-Statut         Germeny         64:01:99         6.3         1.6         1.8         1.8           Markettilla-Statut         Germeny         64:01:99         6.4         1.6         1.8         1.8           Germeny         64:01:90         6.4         1.6         1.8         1.8         1.6         1.8         1.8         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1.6         1	HJ-1-B	China	04/01/08		30, 150, 300	720
Rajadighy-B         Germany         640199         6.3         74           Rajadighy-B         Germany         640199         6.3         78           Rajadighy-B         Germany         640199         6.3         78           Rajadighy-B         Germany         640198         6.3         78           Rajadighy-B         Germany         640198         6.3         78           Rajadighy-B         Germany         640198         6.3         78           Kala         Bagagione         641018         10         50           Hives Baron Smalling         Chine         80.0198         2.5         10         7           Virus         Lange Marce         60198         2.4         14         15         50           Gardighy-1         Grad Schill         100198         2.5         10         7	RapidEye-A	Germany	04/01/08		6.5	78
Repetity-C         Germany         64/31/81         E.4         74           Repetity-C         Germany         64/31/81         5.3         78           Strabarding-C         Germany         64/31/81         5.4         78           Montoffwor-2         G         07/31/81         6.5         1.6         7           Worldfwor-2         G         07/31/81         6.5         1.6         4.5           OWC Stramon-1         Basin         111/50         0.5         1.6         4.5           DMC Contron-1         Spain         111/50         0         1.6         4.5           DMC Contron-1         Spain         111/50         0         1.6         4.5           DMC Contron-1         Spain         10/101/81         2.0         1.6         4.5           DMC Contron-1         Spain         10/101/81         2.0         1.6         4.5         1.7           Algeria         10/101/81	RapidEve-B	Germany	04/01/08		6.5	78
Baskleyn-D         Germany         6401081         4.5         76           Rausber-D         Germany         6401081         4.5         76           Kat         Germany         641081         4.5         7           Kat         Germany         641081         4.5         7           Kat         Germany         641081         4.5         1.8         7           Kat         Germany         641081         4.5         1.8         7           Ward         Germany         641081         4.5         1.8         7           Ward         Germany         641081         4.6         1.8         7           Ward         Germany         641081         0.4         1.8         7           Ward         Germany         641081         0.4         1.8         7           Ward         Germany         641082         0.4         1.8         7           Ward         Germany         641082         0.4         1.8         7           Ward         Germany         641082         0.4         1.8         7           March         Germany         641082         0.7         2.8         60	RanidEva-C	Gormany	04/01/08		6.5	78
Residence         Generatory         6401081         4.5         76           Standard         Surf Africa         6401081         7.5         7           Standard         Surf Africa         6401081         7.5         7           Hines Bencio         China         0101081         7.5         7           Hines Bencio         China         0101081         7.5         7           Marcia         China         0101081         2.5         10         7           Marcia         China         0101081         2.5         10         18           Genetics-1         U.G         6623081         0.4         1.6.4         15           Obschish-1         U.G         6623081         0.4         1.6.4         16           Bill Resourced Standard         U.K         1110808         2.5         2.7         67           Disclash-1         U.K         1110808         2.0         2.8         4.1         10           Bill Resourced Standard         U.K         1110808         2.0         2.8         4.1         10           Bill Resourced Standard         U.K         1110808         2.0         2.8         4.1         10         10	RapidEve.D	Cormany	04/01/08			78
Samith Africa         South Africa         Colore         7.5         7           SAL at the south of	DepidEup E	Commany	04/01/08			78
Same Antra Units         Same Antra Distance         Close (1)         1,3         1,3         1,3           Mines Startic Instance         Close (2)         2,4         1,4         1,4         1,4           Mines Startic Instance         Close (2)         0,4         1,4         1,4         1,4           Mines Startic Instance         Close (2)         0,4         1,6         1,5         1,6	RapidEye-E	Germany	04/01/08		0.0	10
A dat Senare Characterization Insuling and Senare Characterization Insuling Characterization Ins	SumbandilaSat	South Africa	04/01/08		7.5	<u>7</u>
Hunck Sharing         China         070168         2.8,5         10         7           Wins         Large/France         60108         2.8,5         10         24           Card by -1         03         66238         0.4         1.6         24           Card by -1         03         66238         0.4         1.6         24           Dard by -1         03         66238         0.4         1.6         24           Dard by -1         03         66238         0.4         1.6         10           Dard by -1         03         66238         0.4         1.6         10         24           Dard by -1         03         66238         0.4         1.6         10         24           Dard by -1         04         1008         2.5         0         7 <td< td=""><td>x-sat</td><td>Singapore</td><td>04/16/08</td><td></td><td>10</td><td>50</td></td<>	x-sat	Singapore	04/16/08		10	50
Weak/Sime -2 Constant         Uff answer (SecSper-1)         Uff answer (SecSper-1) <thuff answer<br="">(SecSper-1)         Uff answer (SecSper-1)<td>Hi-res Sterio Imaging</td><td>China</td><td>07/01/08</td><td>2.5, 5</td><td>10</td><td>?</td></thuff>	Hi-res Sterio Imaging	China	07/01/08	2.5, 5	10	?
Wrans         Israel/Fance         080109         10         28           Def physical         04         042049         0.4         1.4         50           Dubasita-1         UAR         111508         7         7         7         7           Dubasita-1         UAR         111508         7	WorldView -2	US	07/01/08	0.5	1.8	16
Care Direction         US         062.238         0.4         1.6.4         15           Care Direction         BLA         111.06         7	Venus	Israel/France	08/01/08		10	28
DMC barros-1         Spain         11/1508         Cm         22         660           DARDathoff         LLR         11/1508         7 <td>GeoEve-1</td> <td>US</td> <td>08/23/08</td> <td>0.4</td> <td>1.64</td> <td>15</td>	GeoEve-1	US	08/23/08	0.4	1.64	15
Dublication         UAR         1111038         7         7         7           Dublication         UAR         1111038         7         7         7           Dublication         UAR         1111038         7         7         7           District         UAR         1111038         2.5         2.2         667           Bits ResourceStatic         Model         1211088         6.0         6.23         6.23         6.13           Bits ResourceStatic         Model         070109         0.5         2.8         6.13           Diversition         Model         070109         0.5         3.2         6.13           Diversition         Normal         070109         0.7         6.32         7.8           Diversition         Normal         070109         0.7         6.32         7.8           Diversition         Normal         070109         0.7         6.32         7.8           Diversition         Normal         070109         0.7         6.32         7           Diversition         Normal         070109         0.7         3.8         7           Diversition         Normal         0.30         0.3         3.8	DMC Deimos-1	Spain	11/15/08		22	660
Disc:         UK         1111088         1         22         460           Alarb.A.         Alarb.A.         1011088         2.0         50.5         1.0         51.7         1.0	DubaiSat.1	LIAE	11/15/09	2	-	
Alass 24         Ajorita         129108         2.5         10         7           Mass 24         Hoff         121098         6.2         6.22, 56         7, 44, 67, 76           Bit Resourced 54         Hoff         121098         6.8         6.22, 56         7, 44, 67, 76           CHERS-3         Charabitrazi         600109         5.9         2.0         64, 120           CHERS-3         Charabitrazi         600109         5.9         2.0         64, 120           CHERS-3         Charabitrazi         600109         2.0         1.4         7           ARGO         Tavan         070109         2.0         1.2         7           Pisadan-1         France         030110         0.7         2.8         20           Charabito         070109         6.7         2.8         20         10           Pisadan-1         France         030110         0.7         2.8         20         10           Pisadan-2         France         030111         0.7         3.0         30         30         37           SPOT         France         070112         2.9         6         66         35         37         37           <	DMC LIK-2	UK	11/15/08	1 A A A A A A A A A A A A A A A A A A A	**	660
Andre Sternersekste         Andre Sternersekste         Andre Sternersekste         521.583         24.487.40           CREDSC         Anvaria         640.199         5.0         5.2         5.1           CREDSC         Anvaria         640.199         5.0         2.8         1.1           CREDSC         Anvaria         640.199         5.0         2.8         1.1           CREDSC         Anvaria         640.199         5.0         3.0         46.130           CREDSC         Narraria         0701199         2.5         5.2         2.39           ARGO         Therane         0701199         2.5         5.2         2.39           ARGO         Therane         0701199         2.5         1.0         7           Fileschart         France         030110         2.0         2.8         62           Alex323         Alexapita         120109         2.5         1.0         7           Fileschart         Spaint         070110         2.0         2.8         7           Fileschart         Spaint         070110         2.0         8         7           Fileschart         Spaint         070110         2.0         7         7	Alest 24	Algoric	12/01/08	2.6	10	
non suscentration         non state         12/19/30         6.0         6.73         9.8         2.4, 448, 760           Chensbrack         Comparing         Comparing </td <td>nices and</td> <td>Algena</td> <td>12/01/08</td> <td>2.5</td> <td>10</td> <td></td>	nices and	Algena	12/01/08	2.5	10	
EffO 6         Aural         640199         0         2.3         11           Dire         Mark         640199         0         2.3         140           Dire         Mark         Folder         3         140           Dire         Dire         Dire         2         2         160           Dire         Dire         Dire         Dire         2         2         17           Piezder         Praster         Dire         Dire         Dire         2         17         100         10         10         10         Dire         10         10	IRS Resourcesat-2	India	12/15/08	6.0	0, Z3, 56	24, 140, 740
CBL015-3         Chines/Brazil         60:01:09         2.5         2.0         60.1           Migan         07:01:09         2.5         5.2         2.30           AEOD         Talwan         07:01:09         2.5         5.2         2.30           AEOD         Talwan         07:01:09         2.5         5.2         2.30           AEOD         Talwan         07:01:09         2.5         1.2         2.30           AEOD         Talwan         07:01:09         2.5         1.2         2.30           ABCO         Talwan         07:01:09         2.5         1.2         2.30           ABCO         Talwan         07:01:09         2.5         1.2         2.30           ABCO         Talwan         07:01:09         2.5         1.2         2.30           Pisudes1         Storition         0.5         2.4         20         7           Pisudes2         France         03:01:01         0.5         2.3         2.3         2.3           SPOT         France         03:01:01         0.0         3.3         117           SPOT         France         07:01:12         2.9         6         05           SPO	EROS C	Israel	04/01/09	0.7	2.8	11
TWAAT         India         070109         35         140           Dolt capanization         Name         070109         2.5         3.5         3.0           Dolt capanization         Name         070109         2.7         3.2         7           Mas-23         Apprint         100109         2.0         10         7           Mas-23         Apprint         100109         2.0         10         7           Mas-23         Apprint         070110         5.0         2.0         6           CBER54-4         ChansBitzati         070110         5.0         2.0         7           Finackez         France         835111         0.7         2.1         7           Finackez         France         835111         0.7         2.1         7           Finackez         France         675112         2.0         4         6,100           DCM         UB         070110         10.0         30         107           SPOT         UB         070110         10.0         30         107           SPOT         UB         070110         10.0         30         107           SPOT         ESA         07	CBERS-3	China/Brazil	05/01/09	5.0	20	60, 120
DMC Nigeria         Nigeria         O'01/09         2.5         5.2         220           ARADC         Talwan         0'01/09         6.5         78           ADMASA         Korea         110/09         6.5         78           ADMASA         Korea         110/09         2.5         1.8         7           Resides-1         France         00/01/0         2.7         2.8         2.9           CBERSE-4         CharatTraze         01/01/0         2.8         2.8         2.8           Standard         France         01/01/0         2.8         2.8         7           Standard         France         01/01/0         2.8         2.8         7           Standard         Standard         01/01/0         2.8         2.8         7           Standard         Standard         Other Standard         2.8         7         7           ExMedia         Garwany         01/01/01         2.8         2.8         7         7           SPOT         US         01/01/01         2.0         3.0         177           SPOT         US         01/01/01         2.0         16         6.0         40           Semin	TWSAT	India	07/01/09		35	140
ARGO         Taiwan         0101091         6.8         76           ARGO         Konsta         1010109         0.7         2.8         7           ARGO         Residenti         Ottorio         0.7         2.8         7           Presidenti         Presidenti         Ottorio         0.7         2.8         20           Calcitation         Calcitation         Ottorio         0.7         2.8         20           Presidenti         Chankellow         Ottorio         0.7         2.8         20           Presidenti         Chankellow         Ottorio         0.7         2.8         20           Presidenti         Chankellow         Ottorio         0.7         2.8         20           SPOT         France         0.00111         0.7         3.9         20           SPOT         France         070112         2.9         6         60           SPOT         France         070112         2.9         6         60           SPOT         France         070112         2.9         6         60           SPOT         France         070112         1.0         2.9         6         60           SPOT </td <td>DMC NigeriaSat</td> <td>Nigeria</td> <td>07/01/09</td> <td>2.5</td> <td>5.32</td> <td>320</td>	DMC NigeriaSat	Nigeria	07/01/09	2.5	5.32	320
KOMBAD-3         Korea         110109         0.7         3.2         7           Mak-20         Apprint         100109         2.5         10         7           Mak-20         Apprint         100109         2.5         10         7           Passibility         Transferred         0001110         0.3         20         60,00           SecSd         Spann         0701119         2.5         7         7         7           Passibility         Transferred         S001111         0.7         3         40,00         7           Passibility         Pransferred         S001111         0.7         3         3         60,100         10         3         10         10         3         10 </td <td>ARGO</td> <td>Taiwan</td> <td>07/01/09</td> <td></td> <td>6.5</td> <td>78</td>	ARGO	Taiwan	07/01/09		6.5	78
Alsent2         Algent2         100/198         2.5         10         7           Paralog-1         France         00/110         0.7         2.8         20         60, 10           CBERS-4         ChanatBrazi         070/110         5.0         2.0         60, 120         2.8         20         60, 120         2.8         70         60, 120         2.8         70         60, 120         2.8         70         60, 120         70         70, 120         70         60, 120         70         70, 120         70, 120         70, 120         70, 120         70, 120         70, 120         70, 120         70,	VOMPAT 3	Kasaa	11/01/00		3.3	
Applitus         S001/03         4.0         9.3         52           CRES24         ChardWardl         071/03         5.0         2.0         6.0         1.0           CRES24         ChardWardl         071/03         5.0         2.0         6.0         1.0           Plastate         France         6.0         1.0         7.0         2.0         1.0	Alext 28	Algerta	12/01/09	2.6	10	
Parace         D301/0         0.0         2.4         92           Decide         Spain         0701/0         2.5         7           Decide         Spain         0701/0         2.5         7           Plaudes-1         France         8301/11         0.7         3.7         39           Decide         Output         0.0         2.8         7         1000/10         2.6         7           Plaudes-2         France         8301/11         0.7         3.7         39         100         100         30         117           SPO7         Prace         0701/12         2.0         6         60         40         100         100         30         117           SPO7         Prace         0701/12         2.0         6         60         40         100         100         100         100         20         100	Alberteb	Algena	12/01/09	4.0	10	
CBLPSE-4         ChanaBitrazi         070110         2.5         20         60, 120           Stand         070110         2.5         2.8         5           Stand         070110         2.5         2.8         5           EnMag         Gennary         0701111         3.9         Hp         30           EnMag         US         0701111         0.0         30         177           SPOT         US         0701111         2.0         30         40           SPOT         US         0701111         2.0         40         40           SPOT         US         0701111         2.0         40         40           SPOT         US         0701111         2.0         40         40           SPOT         US         0701173         1.6         6.0         40           Sentral 2.8         E.5A         070173         1.6         5.0         285	Pleiades-1	France	03/01/10	0.7	2.8	20
Secial         Spain         070110         2.5         ?           Pirador-2         France         050111         0.7         2.8         20           Endes         Genary         070111         30 Hyp         30	CBERS-4	China/Brazil	07/01/10	5.0	20	60, 120
Pleades-2         France         0.301111         0.7         2.8         20           EnMag         Germany         070111         30         hyp         30           LDCM         US         070111         10.0         30         117           SPO7         France         070112         2.0         6         60           Sentinel 2 A         ESA         070112         10.20.60         225	SeoSat	Spain	07/01/10	2.5		?
EnMais         Germany         0710111         36 Hpp         36           LDGW         US         0701111         10.0         30         177           SPOT         US         0701111         10.0         30         177           SPOT         2.4         France         070111         2.0         6         60           Sentinet 2.0         E.5A.         070115         10.5         52.5         225	Pleiades-2	France	03/01/11	0.7	2.8	20
LDCM         UB7         0701111         10.0         30         177           SPO7         France         070112         2.0         6         60           Sentinel 2.A         ESA         070112         10, 20, 60         285           Sentinel 2.B         ESA         070113         10, 20, 60         285	EnMan	Gernany	07/01/11		30 Hyp	30
COUM         Op         Or/01/11         10.0         30         17/7           SPOT         France         07/01/12         2.0         6         60           Sentinel 2 A         ESA         07/01/12         10,20,60         285           Sentinel 2 B         ESA         07/01/13         10,20,60         285	LDCH.	course of y	07104/44	****	30 1190	
SPOT         France         0//01/12         2.0         6         60           Sentinel 2 A         ESA         07/01/12         10,20,60         285           Sentinel 2 B         ESA         07/01/13         10,20,60         285	LDOM	05	07/01/11	10.0		
Sentinel 2 A         ESA         07/01/12         10, 20, 60         285           Sentinel 2 B         ESA         07/01/13         10, 20, 60         285	SPOT	France	0//01/12	z.0	6	60
Sentinel 2 B ESA 07/01/13 10, 20, 60 285	Sentinel 2 A	ESA	07/01/12		10, 20, 60	285
	Sentinel 2 B	ESA	07/01/13		10, 20, 60	285

Satellites with ground resolution better than 60 m. Document current as of the end of 2007.

What about before 1984?

From "ASPRS Guide to Land Imaging Satellites", W.E. Stoney, Feb. 2008

Note: Read 4/1 = 1st guarter, 7/1 = in that year, 11 & 12s = late in that year

#### Creating Long Time Series: How far back does the archive goes?

High resolution images acquired before the 1980's:

- Many spy images are now declassified: 860,000 photographs from 1960 to 1972 declassified in 1995 (CORONA, ARGON and LANYARD missions). Ground resolution of 9 m (KH 1-4) and 2 m (KH 4b). 29,000 images from 1970-1980, from KH-9 HEXAGON missions, 7-9m resolution, declassified in 2002. Equivalent declassified programs from the Ex-Soviet Union (Zenit, Kosmos).
- Aerial imagery: In the United States, the U.S. Geological Survey began using aerial photographs for mapping in the 1930's and archives through today are available at about 1 m ground resolution. The NHAP program was initiated in 1980, and NAPP program in 1987 delivered 1 m resolution imagery of the entire US every five years. Archive exist form other agencies (EPA, NAIP, Caltrans, etc...) and many similar programs in most countries.

## Creating Long Time Series: How much aerial data is globably collected?



Average proportion of remote sensing data collected by aerial vs. space-based platforms [ASPRS Ten-year Remote Sensing Industry forecast, Phase V, 2008].

Almost as many aerial data as satellite data collected, potential for a large worldwide archive if imagery can be accessed.

#### What resolution do we have access to?

OPTICAL LAND IMAGING	<b>SATELLITES</b>	BY BEST RES	OLUTION
SATELLITE	PAN RES. M	MS RES. M	SWATH KM
GeoEye-1	0.4	1.64	15
WorldView -1	0.5		16
OulokBird-2	0.5	1.0	16
FROS B1	0.7	2.0	7
EROS C	0.7	2.8	11
KOMSAT-3	0.7	3.2	2
Pleiades-1	0.7	2.8	20
Pleiades-2	0.7	2.8	20
IRS Cartosat 2	0.8		10
RUNUS-2	1.0	-	11
KOMPSAT-2	1.0	4	15
EROS A1	1.8	-	14
FORMOSAT-2	2.0	8	24
THOES	2.0	15	22, 90
SPOT-6	2.0	6	60
SPOT-5	2.5	10	120
IRS Cartosat 1	2.5		30
TopSat (SSTL)	2.5		10, 15
RevekSet*	2.0		30,70
Alsat-2A	2.5	10	2
DMC NigeriaSat	2.5	5.32	320
Alsat-28	2.5	10	?
SeoSat	2.5		?
Hi-res Sterio Imaging	2.5, 5	10	2
Beijing-1 (SSTL)	4.0	32	600
CBERS-3	5.0	20	60, 120
CBERS-4	5.0	20	80, 120
IRS ResourceSat-1	6.0	6 23 56	24 140 740
IRS ResourceSat-2	6.0	6, 23, 56	24, 140, 740
RapidEye-A		6.5	78
RapidEye-B		6.5	78
RapidEye-C		6.5	78
RapidEye-D		6.5	78
RapidEye-E		6.5	78
KOMPSAT-1		0.0	17
SumbandilaSat	0.0	7.5	2
MONITOR-E -1	8.0	20	94, 160
SPOT-2	10.0	20	120
SPOT-4	10.0	20	120
EO-1	10.0	30	37
X-Sat		10	50
Venus	10.0	10	28
Sentinel 2 A	10.0	10 20 60	285
Sentinel 2 B		10 20 60	285
DMC BilSat (SSTL)	12.0	26	24, 52
Landsat 7	15.0	30	185
TERRA (ASTER)		15, 30, 90	60
Proba		18 Hyp	14
CBERS-2	20.0	20	113
DMC Deimon-1	20.0	20	113
DMC UK-2		22	660
Landsat 5		30.0	185
HJ-1-A		30, 100 Hyp	720, 50
HJ-1-B		30, 150, 300	720
EnMap		30 Hyp	30
DMC AlSat-1 (SSTL)		32	600
DMC NigeriaSat-1 (SSTL)		32	600
TWSAT		32	140
		Revised 1/21/08	140
Note: Read 4/1 = 1st guarter, 7/1 = in	that year. 11 & 12s	= late in that year	

Satellites with ground resolution better than 60 m.

Document current as of the end of 2007.

Geomorphology applications stated a need for 10 cm topography accuracy. Could we do it from space?

From "ASPRS Guide to Land Imaging Satellites", W.E. Stoney, Feb. 2008

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

#### What Limits the Resolution of Space Acquisitions?

#### National Defense Authorization Act for Fiscal Year 1997 (S. Rep No.104-278, 104th Cong 2nd Sess., s.1745 (1996):

(Sec. 1044) Prohibits any Federal department or agency from licensing the collection or dissemination by any non-Federal entity of, or from declassifying or otherwise releasing, satellite imagery with respect to Israel and other countries or areas designated by the President, unless such imagery is no more detailed or precise than the imagery of the country or area concerned that is routinely available from public sources.

"Currently, none of our customers outside of the U.S. government can receive imagery better than 0.5 m resolution. Its a limit specified by the government. For the foreseeable future, it doesnt look like 0.5 m resolution will be broken for commercial satellites." Chuck Herring, DigitalGlobe's corporate communications director interview from 01/2008.

This defense limitation explains the large success of aerial imagery for very high resolution applications! Wait, how about 40 cm GeoEye images?

### Ground Resolution Limitation for Commercial Satellites: Slide from Renaud Binet, CEA, last KISS Workshop

Geoeye stereo sub-pixel correlation artifacts



GEOEYE stereoscopic pair, 50cm resolution



0.5 pixel high frequency pattern No subpixel measurement allowed with Geoeye !

KISS Workshop, Caltech, Oct 28th-30th 2009

12

▲ロト ▲ □ ト ▲ □ ト ▲ □ ト ● ● の Q ()

Subpixel artifacts are introduced when the original 40 cm GeoEye images are degraded to 50 cm resolution for commercial customers!

# Very High Resolution Requires using Aerial Photography

Because of space policy limitations, applications requiring very high resolution have to rely on aerial surveys. Aerial photographs commonly acquire images with resolution up to 1-5 cm.

 Unmanned Aerial Vehicles (UAVs) are appearing as a new source of cheap high resolution aerial data.

#### A Distributed Optical Telescope

We propose a **computational framework for subpixel registration** of optical images, **regardless of their acquisition method** and **regardless of their resolution**. In particular, the system could assimilate optical data acquired:

- At any altitude: drones, uav, aircraft, low-orbiting satellites, geostationary satellites (processing methods developed here can be used for the optical Geo-seismometer project),
- From any frame or pushbroom sensors (typical for medium and high resolution imaging).

### A Distributed Optical Telescope

We propose a **computational framework for subpixel registration** of optical images, **regardless of their acquisition method** and **regardless of their resolution**. In particular, the system could assimilate optical data acquired:

- At any altitude: drones, uav, aircraft, low-orbiting satellites, geostationary satellites (processing methods developed here can be used for the optical Geo-seismometer project),
- From any frame or pushbroom sensors (typical for medium and high resolution imaging).

#### Brief Overview of COSI-Corr: Co-registration of Optically

#### Sensed Images and Correlation



◆□▶ ◆□▶ ◆臣▶ ◆臣▶ □臣 = のへ(?)

#### The 1999 Mw 7.1 Hector Mine Earthquake



The Hector Mine horizontal coseismic field (NS and EW) once CCD distortions from SPOT4 and SPOT2 have been modeled during orthorectification. Accuracy better than 1/10 pixel.

#### The Mer de Glace Glacier, France



S. Leprince, et al., EOS, 2008

#### **COSI-Corr Basics**

- Accurate geometrical modeling of pushbroom and frame camera sensors (SPOT 1-5, ASTER, Quickbird, Formosat, Worldview 1-2, aerial sensors),
- In-flight calibration of pushbroom CCD misalignment,
- Subpixel optimization of tie points and ground control points,
- Measurement of ground displacement via multi-scale phase correlation method with accuracy better than 1/10 of the image pixel size,

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

Distributed freely since 2007 via Caltech Tectonics Observatory.

#### Distribution of COSI-Corr Users



## Distribution of registered users. 529 users and 660 downloads as of March 25, 2010

◆□▶ ◆□▶ ◆ □▶ ◆ □▶ ─ □ ─ のへぐ

#### Main COSI-Corr Uses



As reported by users during registration

◆□▶ ◆□▶ ◆ □▶ ◆ □▶ ─ □ ─ のへぐ

### Identified Improvement for Distributed Telescope

- Currently semi-automatic process. Need complete automatic generation of tie points between heterogeneous data,
- Bias and sensitivity to topography errors when measuring ground displacements,
- Loss of resolution when resampling high resolution and high incidence images,
- Need correlation with small window sizes to allow for high resolution topography retrieval,
- Need Accurate estimates of correlation uncertainty to allow assimilation of many correlation results (including topography),
- Need faster processing time,
- Need Bundle block adjustment with aerial photographs,
- Need to better understand and possibly compensate aliasing biases in correlation.

#### Investigated Techniques during Study Period

- Determination of disparities in direction perpendicular epipolar direction to avoid topography sensitivity,
- Rigorous adaptive resampling of high resolution images on very irregular terrain,
- Reproducing aliasing biases via simulation,
- Assimilation of data from different sensors and at different resolution, example on Krafla, Iceland, see next talk by James Hollingsworth,
- Precise determination of uncertainty in correlation estimation to allow for precise assimilation of data, see next Neus Sabater talk,
- Fast multi-processor computing (for large volume and fast response to large disasters - was a limiting factor for Haiti). First proof of concept by Lionel Keene, up to 40 times faster on some processes.

#### Investigated Techniques during Study Period

- Determination of disparities in direction perpendicular epipolar direction to avoid topography sensitivity,
- Rigorous adaptive resampling of high resolution images on very irregular terrain,
- Reproducing aliasing biases via simulation,
- Assimilation of data from different sensors and at different resolution, example on Krafla, Iceland, see next talk by James Hollingsworth,
- Precise determination of uncertainty in correlation estimation to allow for precise assimilation of data, see next Neus Sabater talk,
- Fast multi-processor computing (for large volume and fast response to large disasters - was a limiting factor for Haiti). First proof of concept by Lionel Keene, up to 40 times faster on some processes.



$$D = h(\tan(\theta_1) - \tan(\theta_2))$$

 Measurement error D
 bias ground deformation measurement if the DEM is not accurate. This is often a limiting factor.

▲□▶▲□▶▲□▶▲□▶ □ のQで

▶ D lives in the plane (O₁MO₂), called the epipolar plane.



- Ground deformation measurements will be biased by DEM errors along the epipolar direction.
- No DEM bias in the epipolar perpendicular direction
- Full 2D deformation field can be recovered from three images even if DEM unknown. 3D field with four images.

Study will be presented at IEEE IGARSS in July 2010.



- Ground deformation measurements will be biased by DEM errors along the epipolar direction.
- No DEM bias in the epipolar perpendicular direction
- Full 2D deformation field can be recovered from three images even if DEM unknown. 3D field with four images.

Study will be presented at IEEE IGARSS in July 2010.



Study will be presented at IEEE IGARSS in July 2010.

- Ground deformation measurements will be biased by DEM errors along the epipolar direction.
- No DEM bias in the epipolar perpendicular direction
- Full 2D deformation field can be recovered from three images even if DEM unknown. 3D field with four images.

▲□▶▲□▶▲□▶▲□▶ □ のQで



- Ground deformation measurements will be biased by DEM errors along the epipolar direction.
- No DEM bias in the epipolar perpendicular direction
- Full 2D deformation field can be recovered from three images even if DEM unknown. 3D field with four images.

Study will be presented at IEEE IGARSS in July 2010.



- Ground deformation measurements will be biased by DEM errors along the epipolar direction.
- No DEM bias in the epipolar perpendicular direction
- Full 2D deformation field can be recovered from three images even if DEM unknown. 3D field with four images.

Study will be presented at IEEE IGARSS in July 2010.

#### Orthorectification: An Irregular Mapping



Resampling irregularities depend on the local viewing angle and topography gradient. They increase with image resolution and can vary by up to a factor of 10 in high resolution images over steep topography.

### Rigorous Adaptive Resampling: principle



- Kernel locally warped according to local mapping warp (linearized locally = Jacobian of projection mapping)
- Use approximated sinc kernels-like kernels to preserve subpixel information and limit aliasing.

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

### Rigorous Adaptive Resampling: equivalent kernel

General resampling kernel in sensor geometry:

$$\rho_s(\mathbf{x}) = r_s(\mathbf{x}) \circledast h_g(\mathbf{J}\mathbf{x})|\mathbf{J}|,$$

- *r<sub>s</sub>* reconstruction kernel defined in sensor geometry,
- ▶ *h<sub>g</sub>* anti-aliasing filter defined in the mapped geometry (on the ground),

- ロト・ 日本・ モー・ モー・ うらく

**J** Jacobian of the warping function.

#### A new kernel is computed at each resampling point

Study will be presented at IEEE IGARSS in July 2010.

#### Rigorous Adaptive Resampling: demonstration for simple cases

45 degrees rotation







Kernel Spectrum

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

### Rigorous Adaptive Resampling: test case in glaciology



Adaptive resampling



Non-adaptive resampling



Images courtesy of D. Quincey

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

### Aliasing Biases in Correlation



### Aliasing generated artifacts in EW correlation results Aliasing artifacts can be reproduced in simulation



#### ▲□▶ ▲□▶ ▲三▶ ▲三▶ 三三 のへの

#### Scheduled Studies and Collaborations

#### Technical:

- Multiprocessor programming and fast algorithms implementation (Lionel Keene),
- Characterization of aliasing bias in correlation measurements (3 months summer internship),
- Automatic robust tie point selection and subpixel bundle block adjustment (6 months internship),
- High resolution disparity determination (Neus Sabater).

#### Thematic:

- Changes in the hydrologic and glacial regime in High Asia (Bodo Bookhagen),
- River hydrology and geomorphology, and landslides evolution in California Mike Lamb and students

< □ > < 同 > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

#### Long Term Questions to be Investigated

- Effects and compensation of shadowing changes,
- Integration with SAR data,
- Effects of change of incidence angle on reflectivity to produce radiometrically correct ortho-images,
- ▶ Integration with Lidar and retrieval of 3D deformation from Lidar.

#### Conclusion:

- We propose a computational framework to enable global monitoring of Earth surface changes using past, current and future imaging systems.
- Techniques developed would also work for the geostationary project to be presented by Remi Michel,
- Large implication for Earth Sciences, e.g., global monitoring of mountainous glaciers, landslides, sand dunes migration, desertification, earthquakes, volcanoes, land monitoring, agriculture, deforestation, etc...
- Optical imaging satellites have not yet been designed for measuring ground deformation. Earth Sciences applications put new constraints on the design of future missions, and we started to investigate the design of a small satellite that would monitor the evolution of topography. Collaboration with Sergio Pellegrino's KISS study on large space structures, discussion on Wednesday morning March 31st.

#### The End: Thank you!



#### Research.



Here, we propose an automated procedure that overcomes most of these limitations. In particular, we elevation models with global coverage (ERTN). This methodology uill improve autoality to collact measurements of ground deformation, in particular in measurements of ground deformation, and the little or no local geophysical infra-turburburb. Measuring co-selemic deformations from remotely temped optical margins is attractive thank is the ground to the turbal number of imaging programs (EPCT, ARTRK, Gueblich), availability of attributed data.

The general procedure consists of generating accurate ground control points (GCP) for each image. An accurate ortho-rectification model is then built, which allows accurate ortho-rectification and co-registration of the set of images. Correlation on the ortho-rectified images then delivers the horizontal ground displacements to analyse. The algorithms described in this study have been implemented in a software package, COSI-Corr (Correlator), developed vith IDC (Interactive Data Language) and integrated under EWI. It allows for precise who-restification, corregistration and correlation of SPOT and ASTER satallite images as well as tensis photography.

User's Guide 🚻

COSI-Corr is now available.



#### 2006 ience, Editors' Choice:

ne Big Dig Wouac et al. show the Mv 7.6 (ashmir earthquake rupture rroke through to the surface.

#### 8/2006 Nature, Research Highlig Satellite maps faultline

essearchers use readily avai atellite photographs to mea round déformation caused l arge carthquakes.

