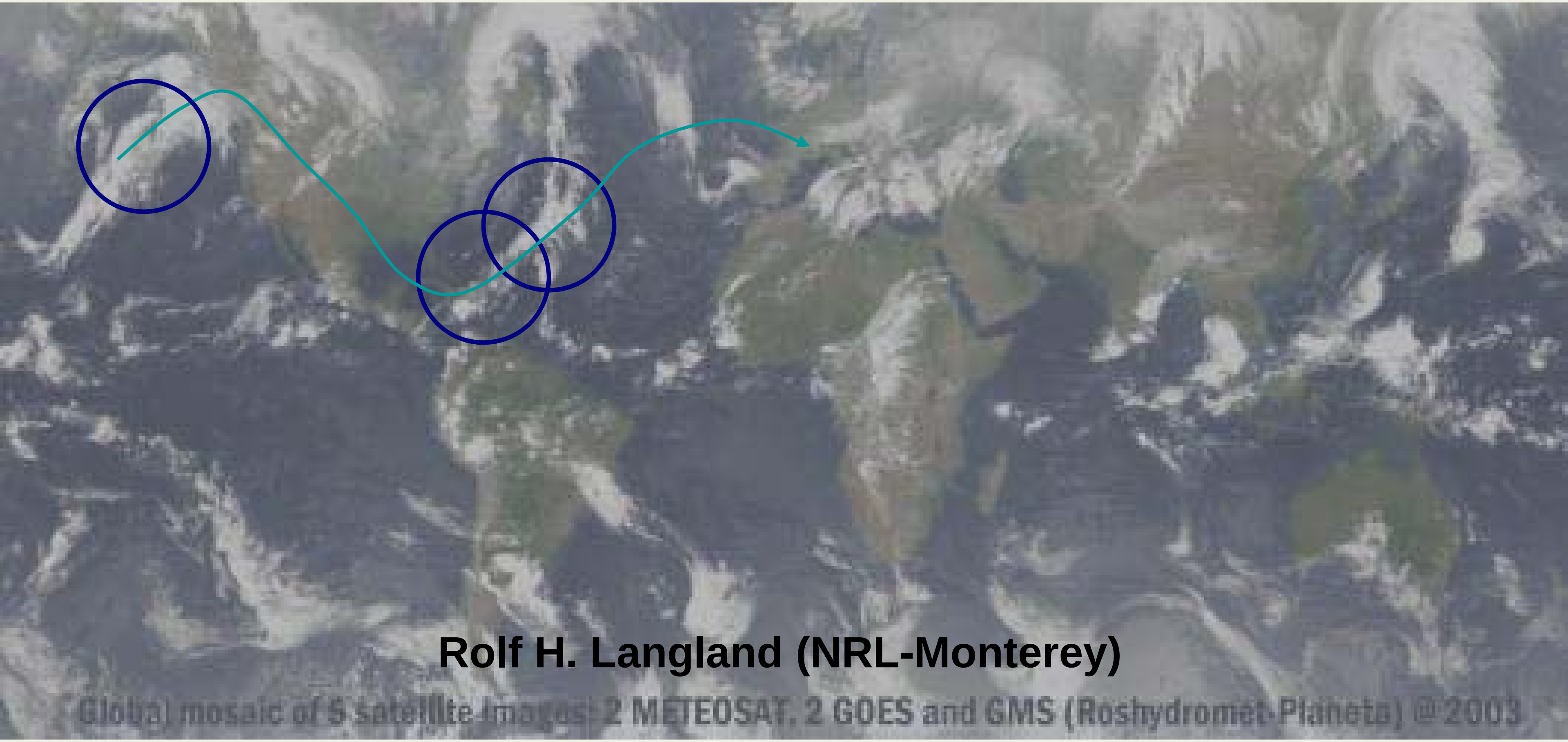
Overview of Adaptive Observing



Rolf H. Langland (NRL-Monterey)

JCSDA Summer Colloquium on Data Assimilation

Stevenson, Wash, 16 July 2009

Outline of Presentation

- **What is adaptive (or "targeted") observing?**
- **Review of targeting programs (1997-2009)**
  - methodologies, results, interpretations
- **New concepts of adaptive observing --**

Note: this talk describes adaptive observing for *atmospheric* applications – *ocean* adaptive observing techniques have also been developed

What is Targeted Observing ?

If one has the capability to add ~10-10,000 special atmospheric observations to improve the forecast of a particular weather event, can the locations be determined using objective (e.g., model-based) methods?

Optimization problem with two constraints…

1. The probability of making an analysis error at a particular location
2. The intrinsic instability of the flow in that locations…sensitivity

Can the data assimilation method accurately incorporate the special observations?

Goal is not to correct the largest analysis error, but the analysis error that leads to the largest forecast error

Field Programs for Targeted Observing

Programs for winter storm targeting

- **North Atlantic (FASTEX-1997, ATREC-2003)**
- **Eastern North Pacific (NORPEX-1998, WSR-1999-2009)**
- **Entire North Pacific (Winter T-PARC 2009)**

Programs for hurricane / tropical cyclone targeting

- **North Atlantic (NOAA-HRD, 2000-2009)**
- **Western Pacific (DOTSTAR, 2003-2009)**

  T-PARC (TCS-08) 2008

***Participants**: Meteo France, ECMWF, UKMO, NRL, NCEP, NCAR, NOAA-AOC, NOAA-HRD, USAF Hurricane Hunters, NASA, CIMSS, MIT, Univ. of Miami, Penn State Univ., others*

Targeting Paradigms

1997- present

Dropsonde Targeting

- Improvement of single forecast
- Identify “target of the day”
- Intermittent observing
- Small sets of observations
- Small observing area
- Small forecast impact
- 20-30% of forecasts degraded

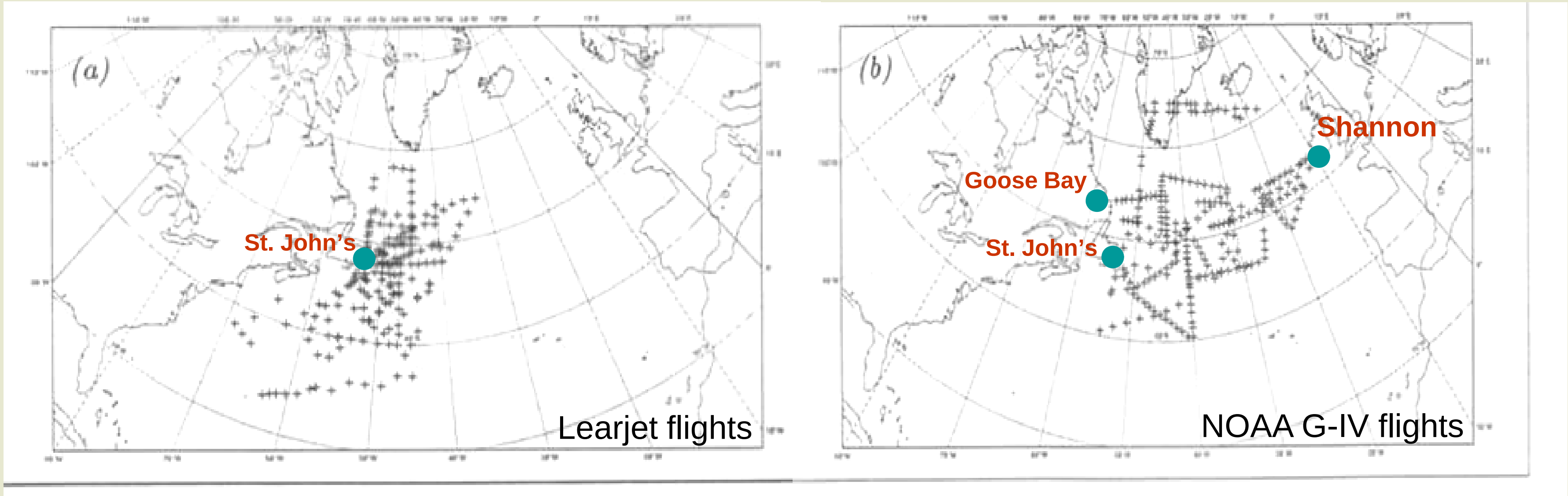
2008 - present

Satellite Targeting

- Improve sequence of forecasts
- Target based on flow-regime
- Continuous observing
- Large sets of observations
- Regional observation area
- Larger forecast impact
- Fewer degraded forecasts

FASTEX – first targeted observing program

January – February 1997



12 targeted dropsonde missions tasked by NCEP and NCAR

8 targeted dropsonde missions tasked by Meteo France & NRL

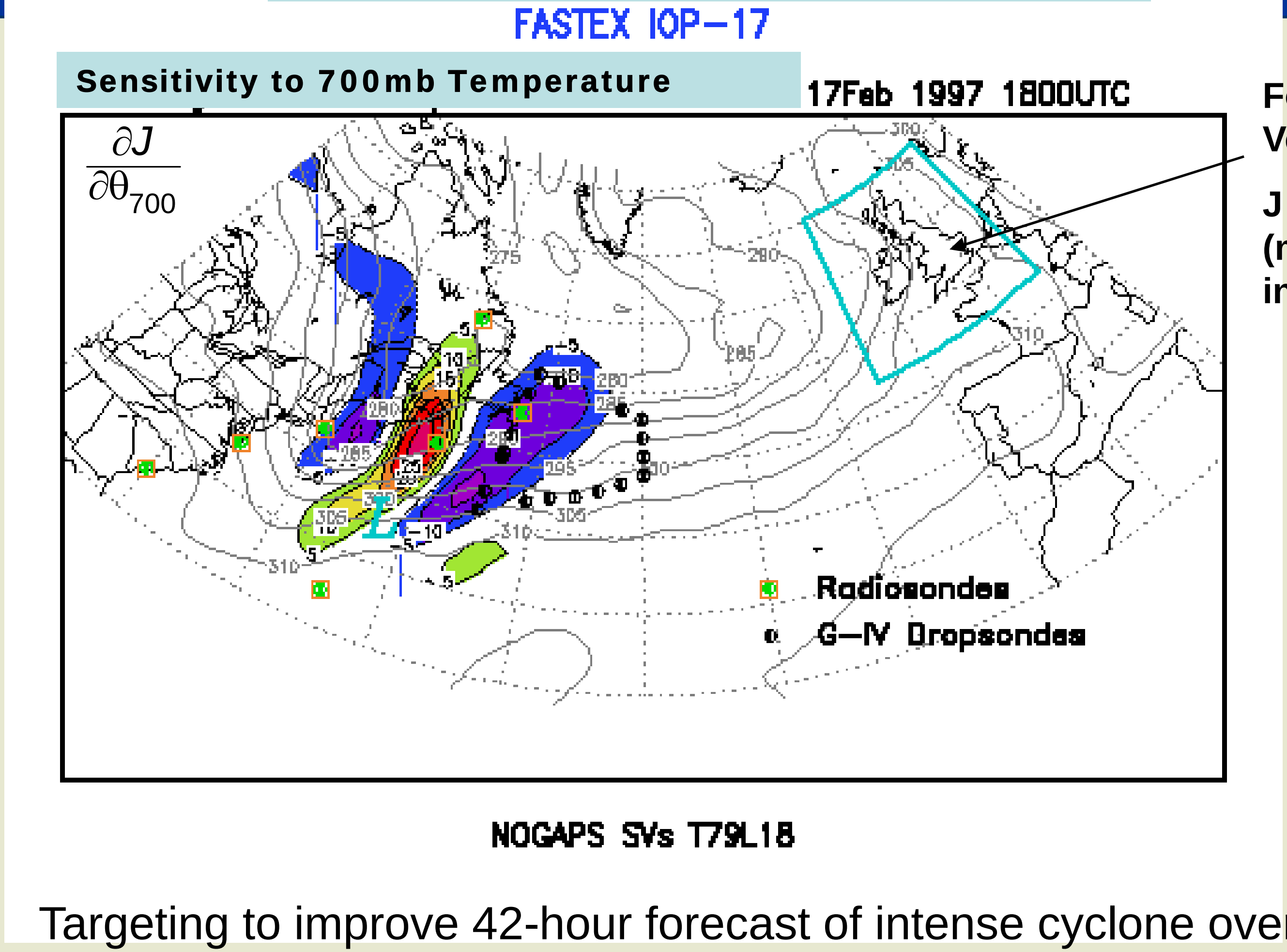
Figure from T. Bergot

Twelve years since the first targeting field program

FASTEX Targeting Flight – Meteo France / NCAR / NRL / NOAA

Goose Bay, Canada – 22 Feb 1997 – IOP-18

Adjoint-based Targeted Observing



Forecast Verification Region

J = Vorticity (measure of cyclone intensity)

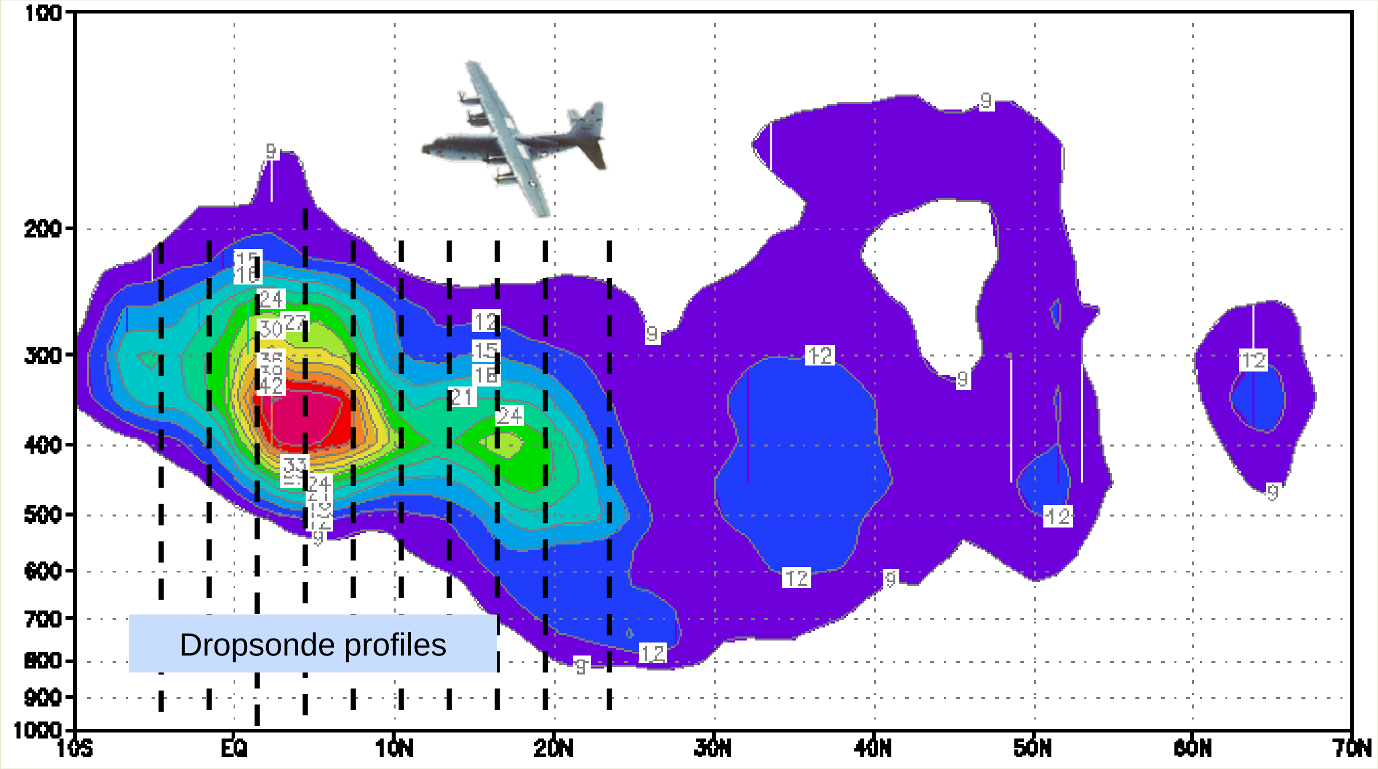
Targeting to improve 42-hour forecast of intense cyclone over Ireland and Great Britain

The “target region”

- A region in which initial condition error is expected to cause significant forecast error or uncertainty at the forecast verification time
- Occur in dynamically significant regions (baroclinic zones, strong advection, jet entrance / exit)
- The key initial “error” may involve relatively small changes to temperature and wind structure
- Does not necessarily correspond to most prominent synoptic features (surface low, PV max)

Vertical cross-section of sensitivity information from NOGAPS adjoint model

Jet Stream Level



Surface Level

Dropsondes provide vertical profiles of temperature, wind, and humidity in region of maximum dynamic sensitivity (error source region)

Targeting Methodologies

Early (1997-1998)

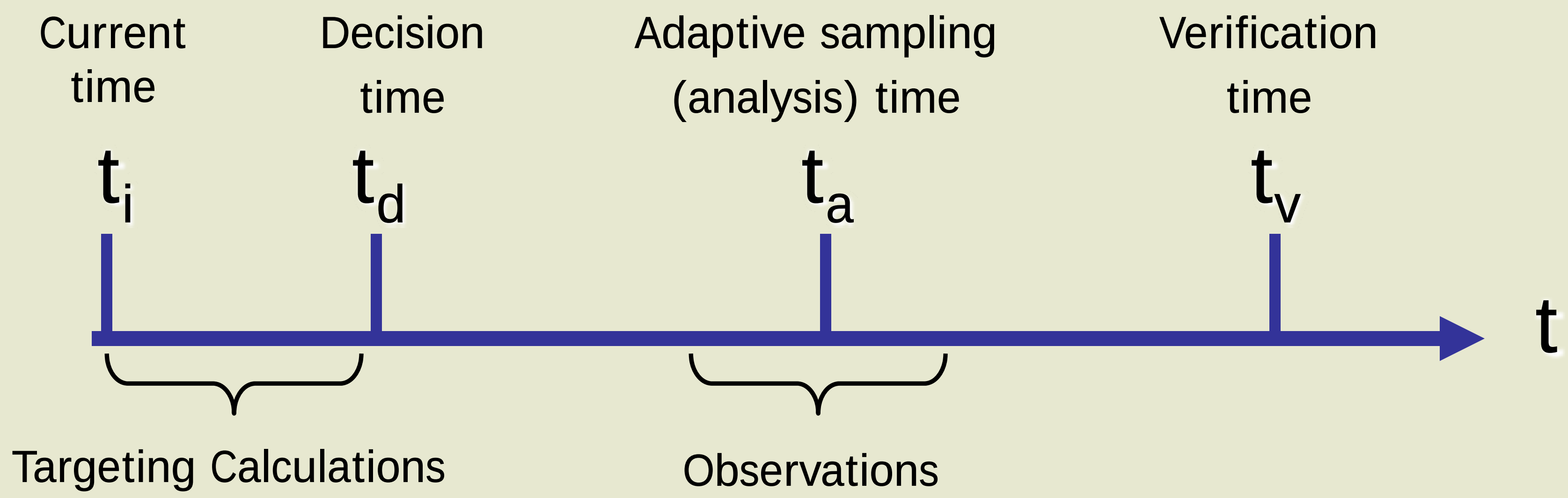
- ***Total Energy Singular Vectors –*** ***smaller-scale, tilted, mid-lower troposphere***
- ***Ensemble Transform –*** ***larger-scale, barotropic, upper troposphere***
- ***Inverse Tangent Linear Model***
- ***Potential Vorticity***

More Advanced / Current (1998-2009)

- ***TE, Hessian, and Moist Singular Vectors***
- ***Ensemble Transform Kalman Filter***
- ***Direct Sensitivity to Observations***

Contributors*: Baker, Barkmeijer, Bergot, Bishop, Buizza, Cardinale, Daley, Doerenbecher, Emanuel, Errico, Etherton, Fourrie, Gelaro, Hello, Joly, Kalnay, Langland, Leutbecher, Lorenz, Majumdar, Malardel, Montani, Morgan, Morss, Palmer, Pu, Rabier, Reynolds, Rohaly, Rosmond, Shapiro, Snyder, Szunyogh, Thorpe, Toth, others*

Target Planning Time-Line



How do we choose the optimal deployment of observations to improve a forecast between times t_a and t_v?

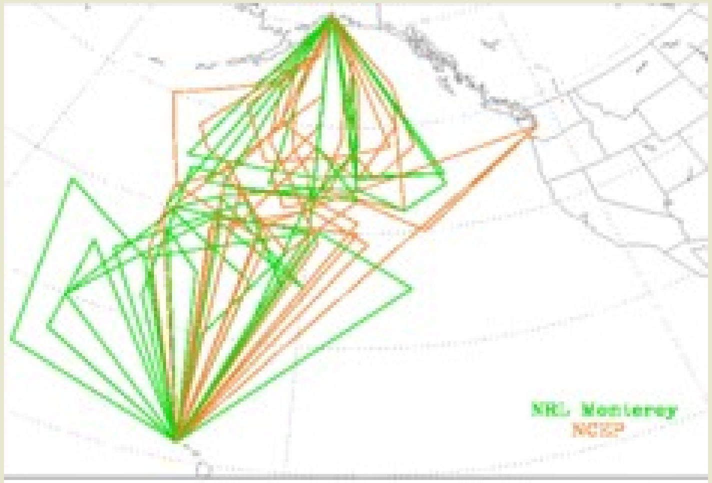
Impact of NORPEX targeted dropsondes

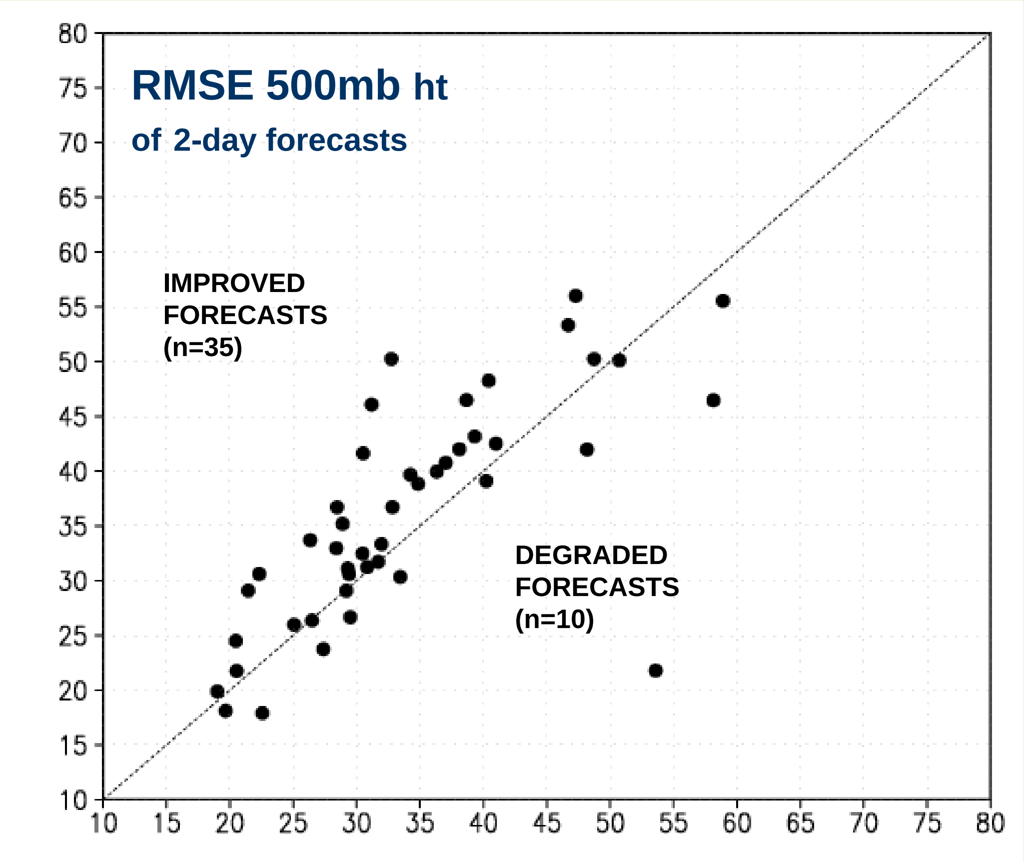
16 January – 27 February 1998 (NRL-NCEP)

In 45 forecast cases, ~ 10% mean error reduction over western North America, using NOGAPS forecast model

Approx 700 dropsondes

45 forecast cases





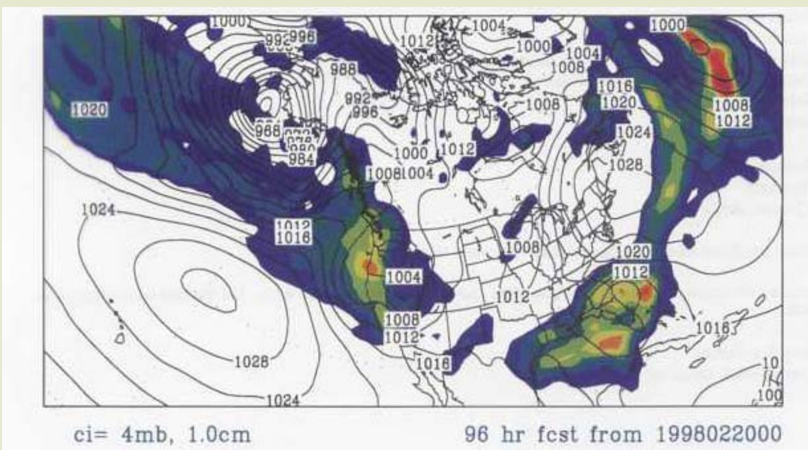
error with targeted dropsondes (m)

Langland et al. 1999 (BAMS)

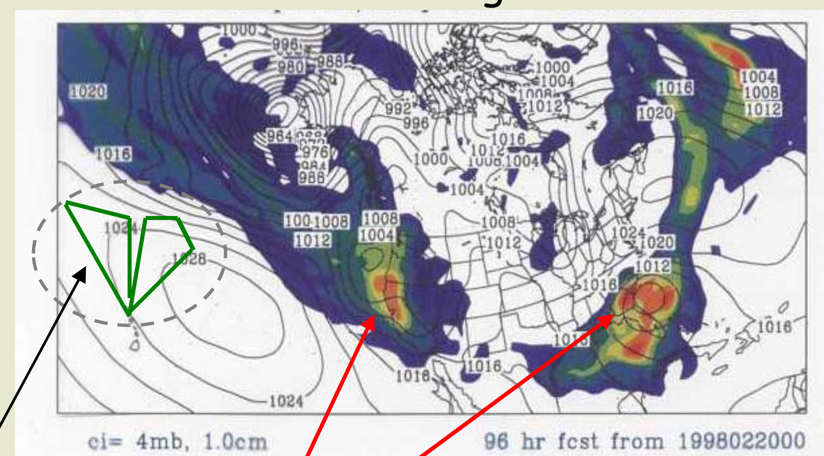
Targeted Observing Impact

Impact of 30 dropsondes on a 96-hr NOGAPS Forecast during NORPEX (Feb 1998)

Control Forecast



Forecast with Targeted Data



Target Region for special dropsonde observations

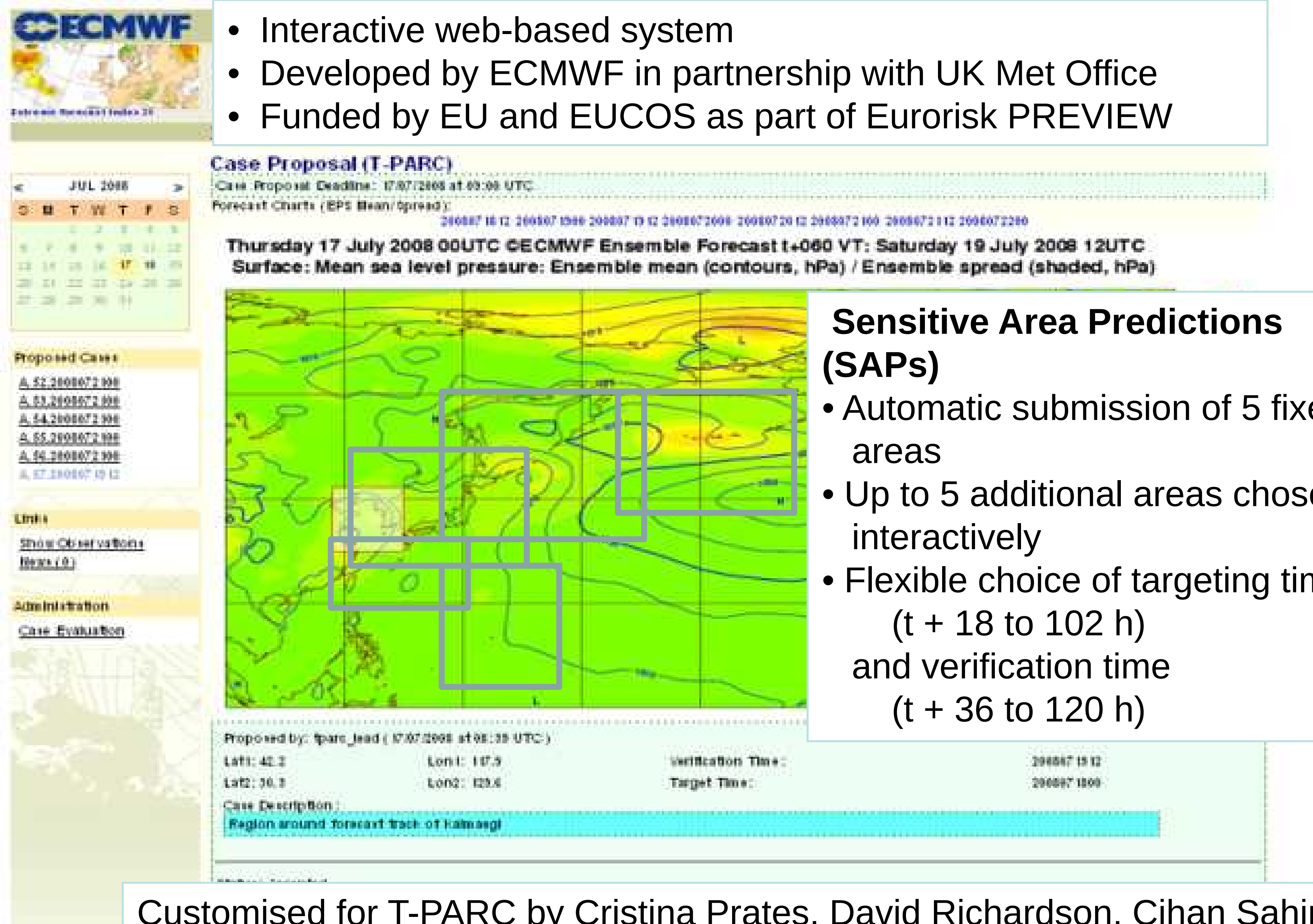
Significant Enhancement of Precipitation in Storms over California and Florida

TCS-08 Targeting Groups

Center	Presenters	Date and Time	Targeting Method	Evaluation model
JMA	Bessho, Komori, Nakazawa, Yamashita	2 talks Mon 2 posters Mon	SVs / all drops	JMA
DLR	Weissmann, Harnisch	Talk Mon Poster Mon	all drops	ECMWF
ECMWF	(contact: Richardson)		SVs	
UKMO	(contact: Swinbank)		ETKF (MOGREPS)	
U Miami/NCEP	Majumdar, Song		ETKF (NCEP + ECMWF + CMC)	
NRL	Reynolds, Langland	Poster Mon	SVs	NOGAPS
NRL	Doyle		COAMPS Moist Adjoint	
U Yonsei	Kim, Jung	Talk Mon Poster Mon	SVs	MM5
U Washington	Hakim	Talk Mon	Ensemble sensitivity	WRF

Data Targeting System

- Interactive web-based system
- Developed by ECMWF in partnership with UK Met Office
- Funded by EU and EUCOS as part of Eurorisk PREVIEW



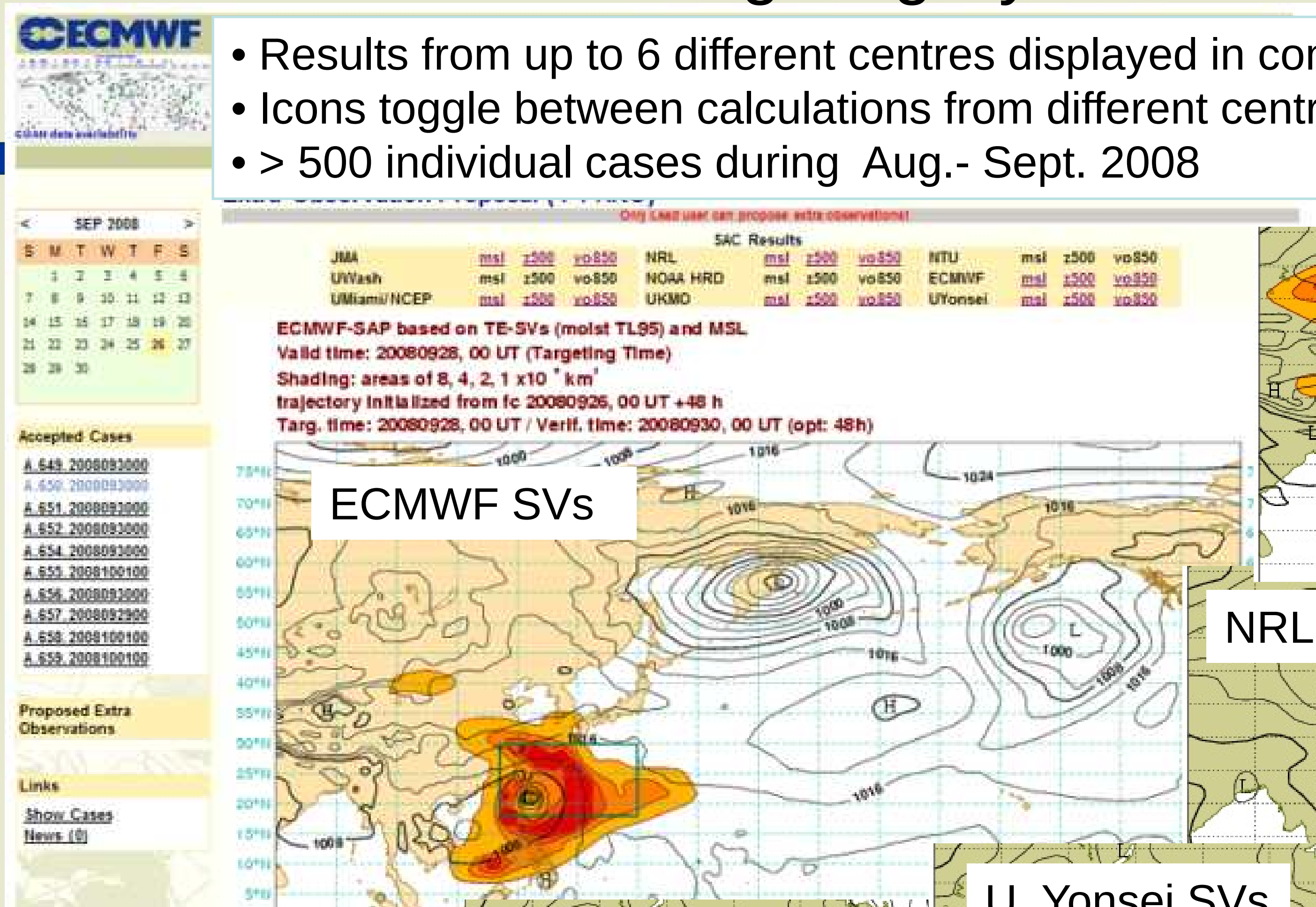
Sensitive Area Predictions (SAPs)

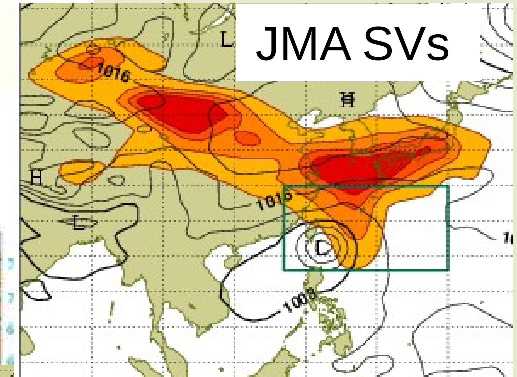
- Automatic submission of 5 fixed areas
- Up to 5 additional areas chosen interactively
- Flexible choice of targeting time (t + 18 to 102 h) and verification time (t + 36 to 120 h)

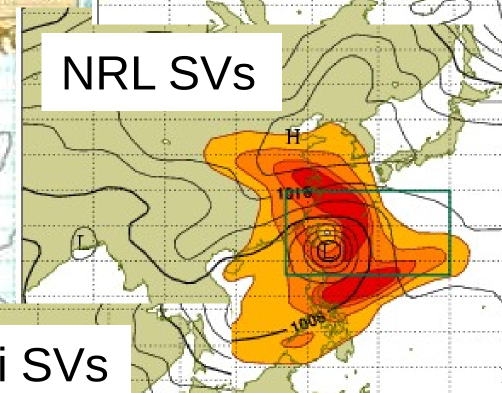
Customised for T-PARC by Cristina Prates, David Richardson, Cihan Sahin

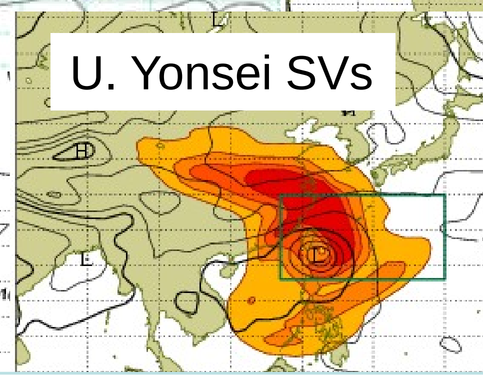
Data Targeting System

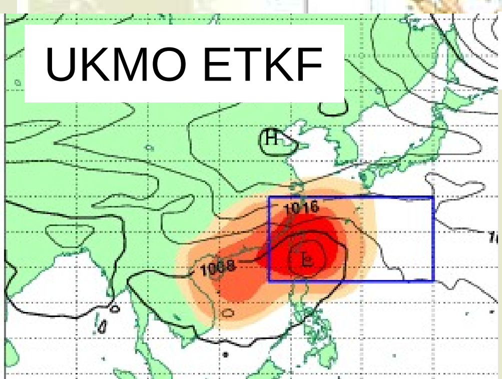
- Results from up to 6 different centres displayed in common format
- Icons toggle between calculations from different centres and overlays
- > 500 individual cases during Aug.- Sept. 2008

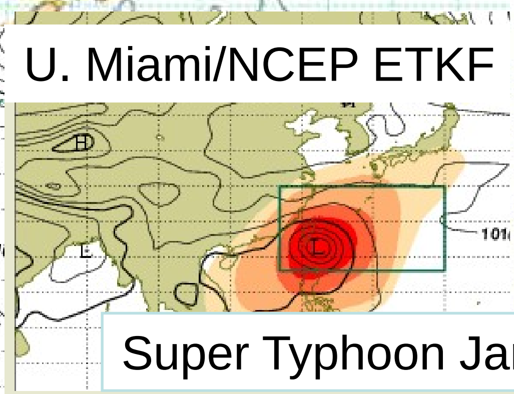






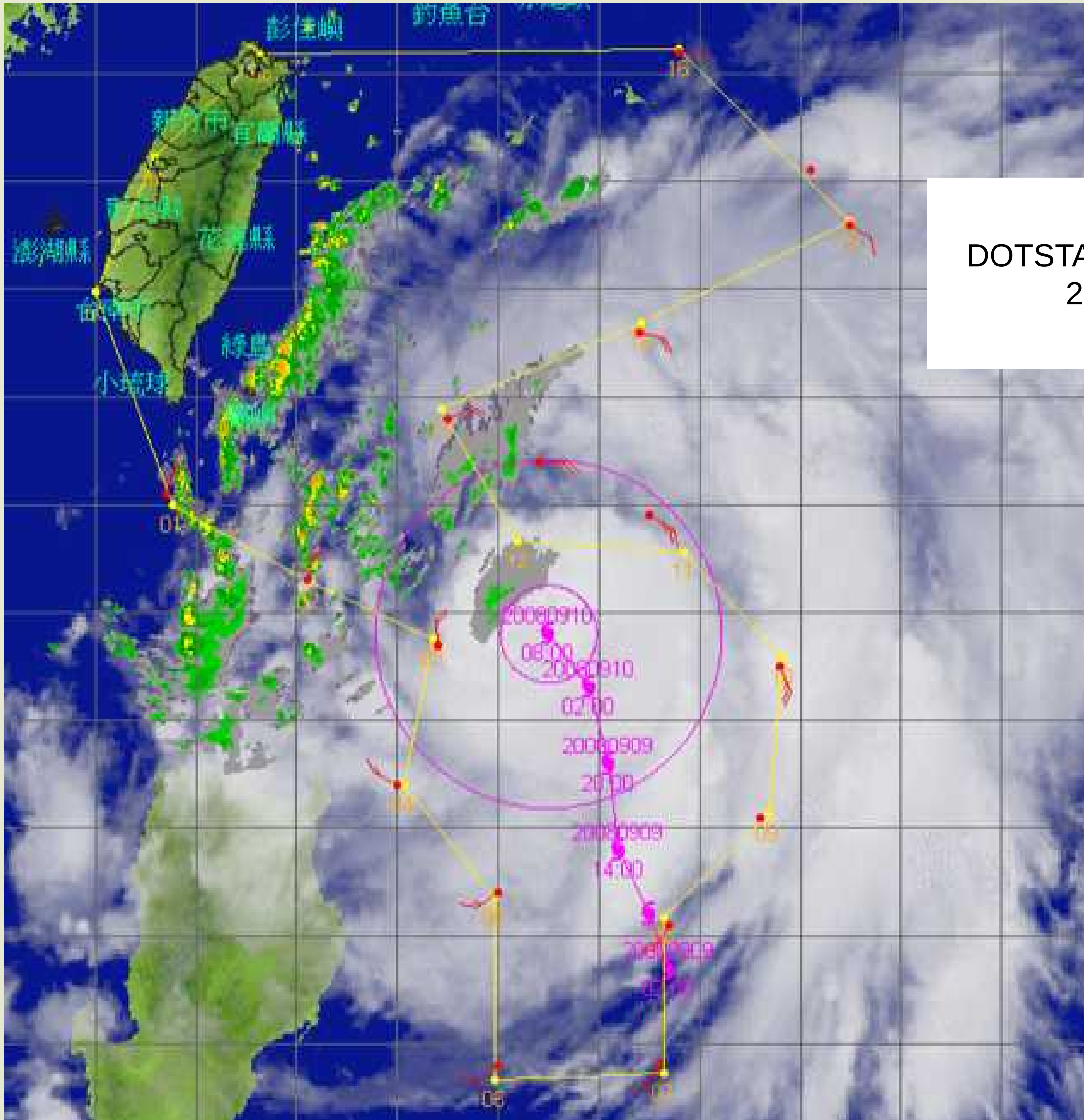






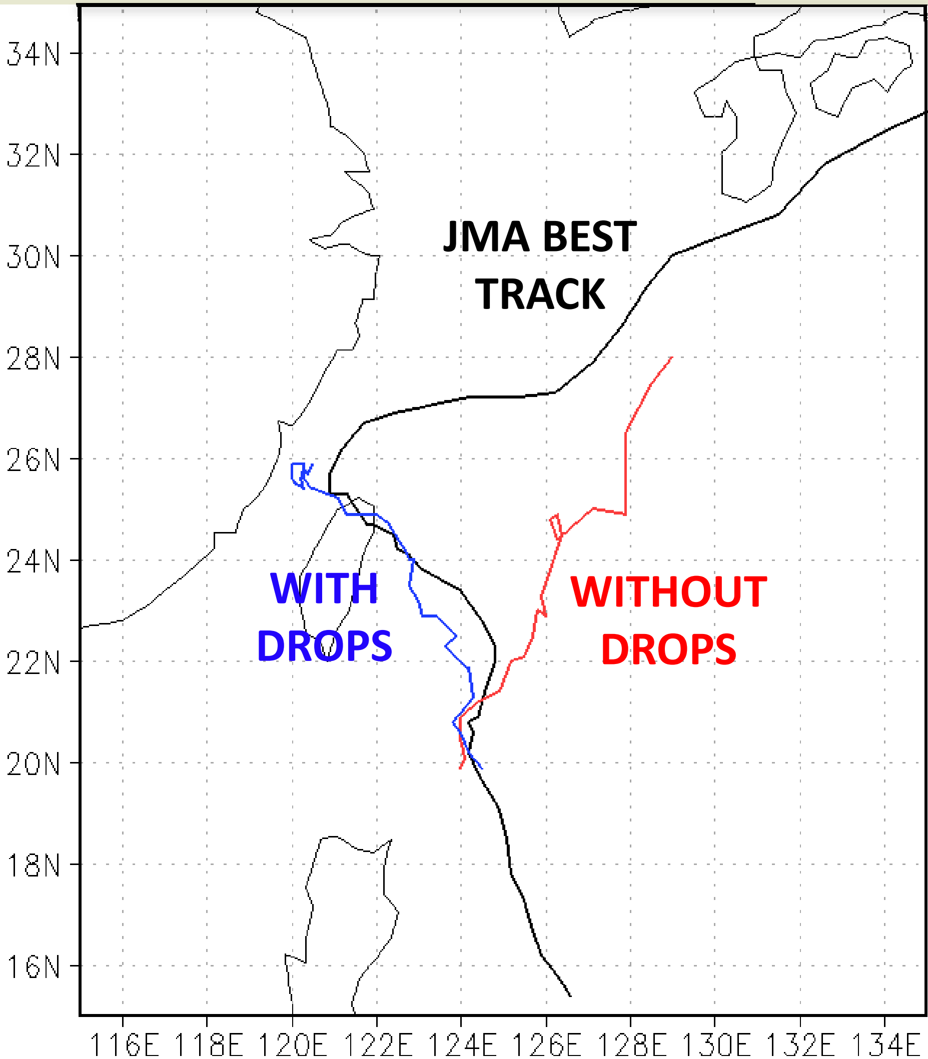
Super Typhoon Jangmi: Targeting Time 28 Sept. 2008

Sinlaku Targeting
TCS-08

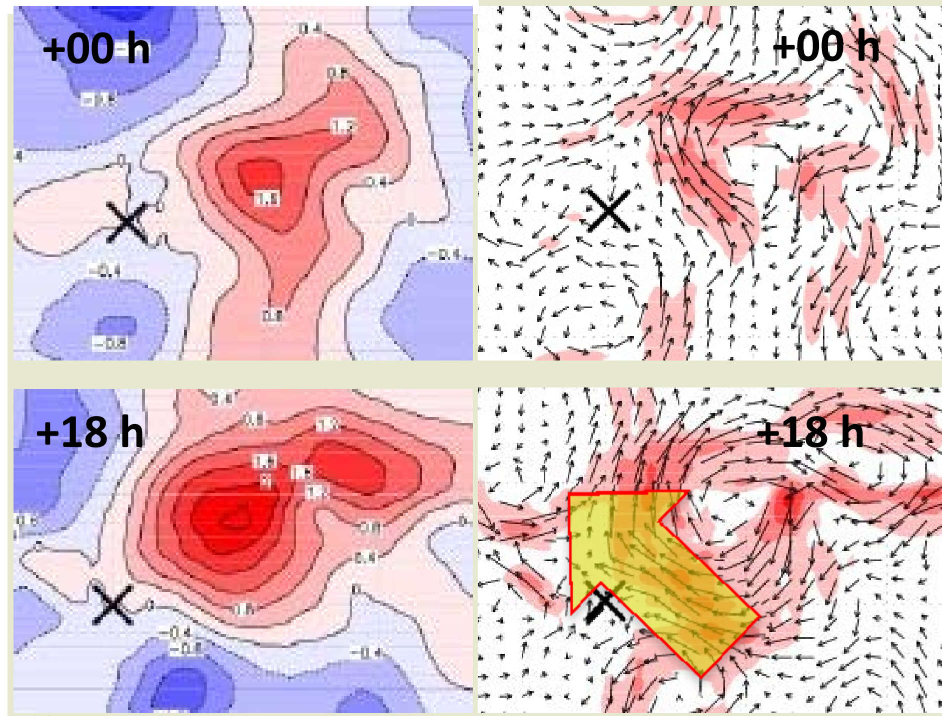


DOTSTAR Mission,
2008091000

Preliminary Result: Sinlaku
NCEP GFS initialized 00 UTC 10th Sept



500 hPa ASYMMETRIC STREAMF'N DIFF | **500 hPa ASYMMETRIC WIND DIFF**



Effect of drops:
Strengthened vortex and subtropical ridge, inducing northwestward flow

Courtesy of Sharan Majumdar, Univ. Miami

Does “Targeting Work”?

Yes - however ……

- Dropsonde targeting provides only partial surveys of target areas
- No definitive consensus on which targeting method is most accurate - targeting data sets are not adequate to compare impacts in “competing” target areas (SVs vs ETKF)
- Impact of targeted observing on medium-range forecasts requires additional studies

Targeting Field Program Results -1

***Logistical:** It has proven feasible to prepare targeting guidance ahead of time, and deploy in-situ observational resources (e.g., dropsondes) for at least partial coverage of the identified target regions*

***Synoptic Interpretation:** Analysis errors in the mid-lower troposphere are at least as important as PV-tropopause errors for predictability of extratropical winter cyclones*

***Error subspace:** A large fraction of fast-growing forecast error is explained by projection onto the leading singular vectors – error propagates at group velocity – downstream development -*

***Prediction of large-error cases:** Targeting methods do not always anticipate which cases will have the largest forecast error*

Targeting Field Program Results -2

Forecast Impact of Targeted Data – (adding 10-50 dropsondes at single assimilation times)

- ***Targeted data improves the <u>average skill</u> of short-range forecasts*, by ~ 10–20% over localized verification regions – maximum improvements up to 50% forecast error reduction in localized areas***

- ***In all analysis / forecast systems*, and for all targeting methodologies, it is found that ~ 20-30% of forecast cases are neutral or degraded by the addition of targeted data***

- ***Impact "per-observation" of targeted data is large, but total impact is generally limited by the relatively small amount of targeted data***

*** Results based on published forecast impact studies performed at NCEP, ECMWF, Meteo France, UKMO, NRL**

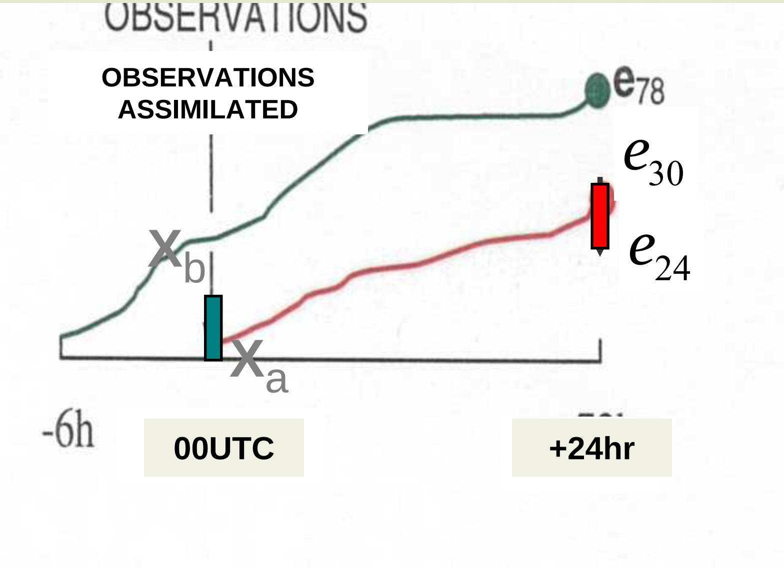
Targeting and Observation Impact Questions

Why does assimilation of “good observations” make some forecasts worse ?

Why doesn’t the assimilation of 10-50 dropsondes produce larger impacts on forecast skill?

Examine the data assimilation procedure →

Impact of Observations on Forecast Error



The forecast error difference, $e_{24} - e_{30} = \Delta e_{24}^{30}$, is due to the assimilation of observations at 00UTC

Langland and Baker (Tellus 2004)

Use of a Data Assimilation Adjoint to Evaluate Observation Impact

ADJOINT OF DATA ASSIMILATION

30h e-weighted forecast error norm – global domain

$$\delta e_{24}^{30} = \left\langle (\mathbf{y} - \mathbf{H}\mathbf{x}_b),\ \mathbf{K}^T \left(\frac{\partial J_{24}}{\partial \mathbf{x}_a} + \frac{\partial J_{30}}{\partial \mathbf{x}_b} \right) \right\rangle$$

OBSERVATION IMPACT ON FORECAST ERROR
(J kg^{-1}) – units of energy

INNOVATION

SENSITIVITY GRADIENTS FROM ADJOINT OF GLOBAL FORECAST MODEL

< 0 = BENEFICIAL

> 0 = NON-BENEFICIAL

Observation impact interpretation -

For any observation / innovation … using this error measure

$\delta e_{24}^{30} < \mathbf{0.0}$ **the observation is BENEFICIAL**

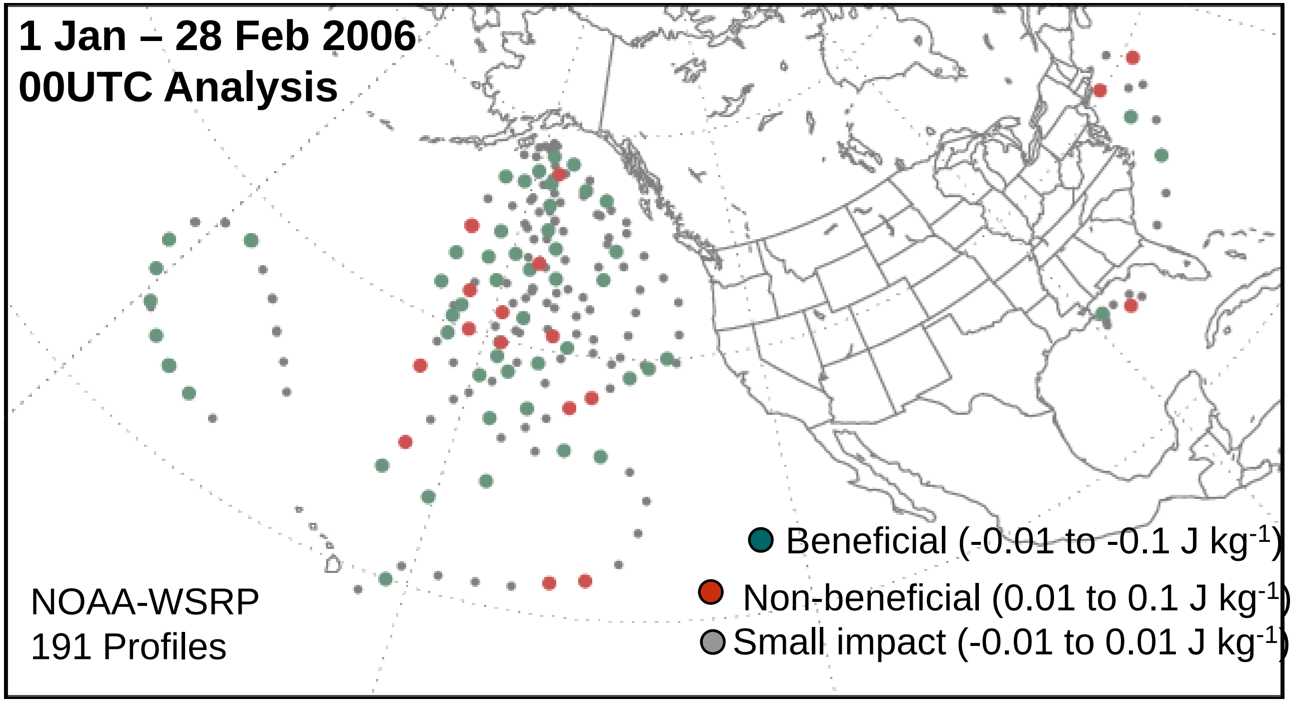
the effect of the observation is to make the error of the forecast started from $\mathbf{x_a}$ less than the error of the forecast started from $\mathbf{x_b}$, e.g. forecast error decrease

---

$\delta e_{24}^{30} > \mathbf{0.0}$ **the observation is NON-BENEFICIAL**

e.g., forecast error increase

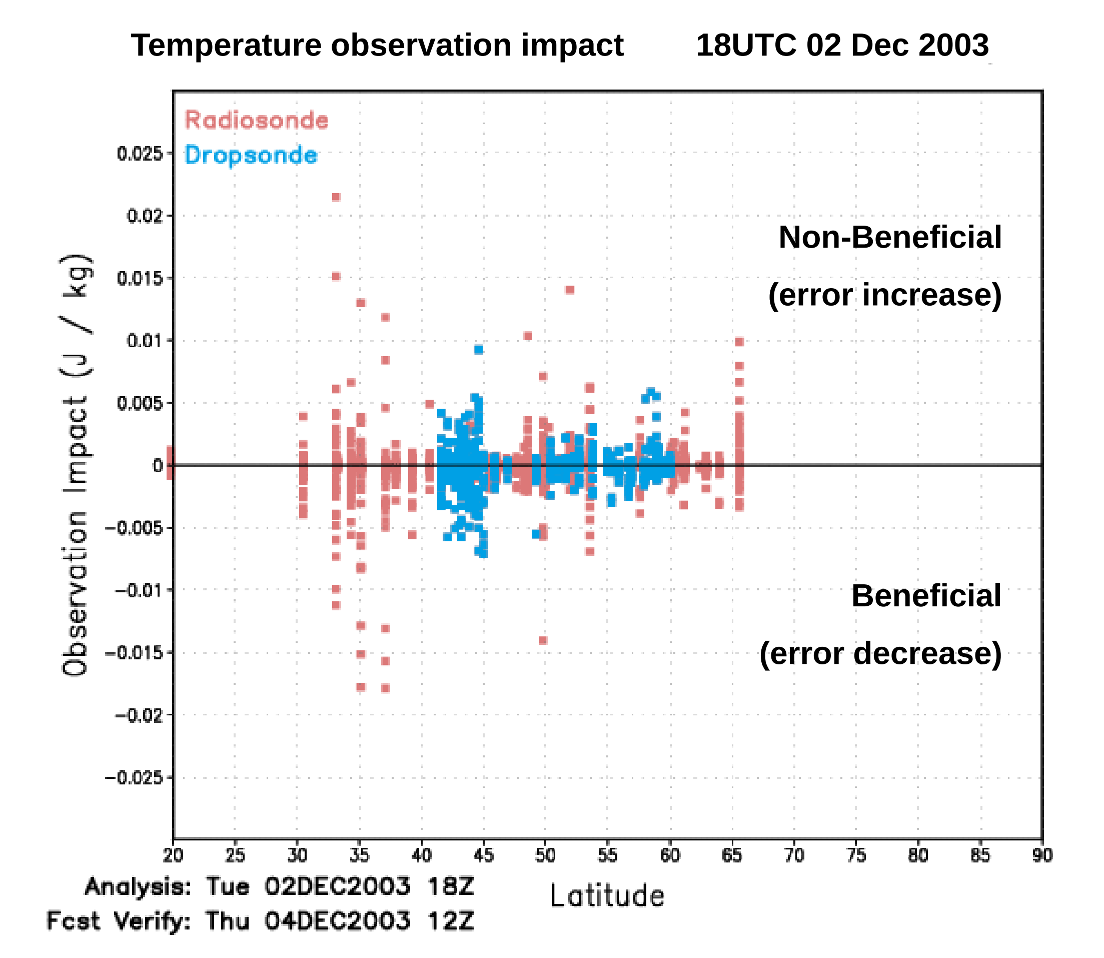
USING ADJOINT-BASED OBSERVATION IMPACT TO EVALUATE WSR DROPSONSDES



Date: Jan-Feb 2006

Result: Average targeted dropsonde profile impact is beneficial – placement in sensitive regions provides 2-3x larger impact than average radiosonde profile

NA-Trec Targeting Case
Dropsonde & Raob impact on 42hr error



Dropsondes (689 data)

$$\delta e_{42}^{48} = -0.0945 \ \mathrm{J\,kg^{-1}}$$

Radiosondes (2096 data)

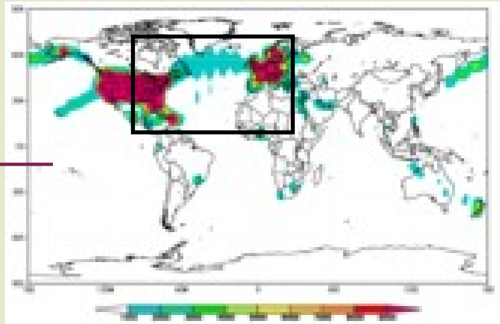
$$\delta e_{42}^{48} = -0.2077 \ \mathrm{J\,kg^{-1}}$$

Impact of **all 18UTC observations** located in NA-TReC domain 1Nov - 31Dec 2003

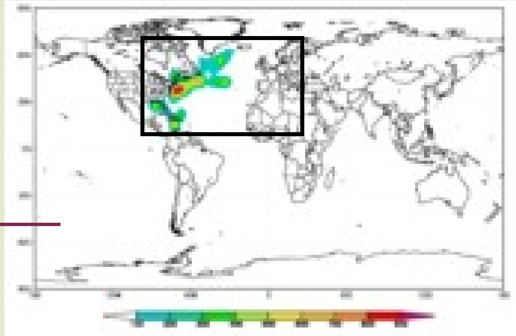
Observation Type 18UTC	δe_{42}^{48} (J kg^{-1})	% of total	# obs	δe_{42}^{48} per ob (10^{-5} J kg^{-1})
Aircraft	-17.54	46.3%	1,658,355	-1.1
AMSU-A	-5.86	15.5%	739,547	-0.8
Geosat winds	-5.18	13.6%	621,526	-0.8
Land-surface	-3.53	9.3%	304,766	-1.2
Rawinsondes	-3.06	8.1%	202,522	-1.5
Ship-surface	-2.04	5.4%	98,796	-2.1
Dropsondes	-0.67	1.8%	13,418	-5.0
Total	-37.88	100%	3,638,930	-1.0

Forecast impact measured in global domain

aircraft data count



dropsonde data count



Dropsonde data targeted to sensitive areas has high impact per-ob

Increasing the impact of targeted observing

Goal 1: Increase the average beneficial impact of targeted data in deterministic and ensemble forecasts –

Goal 2: Increase the percentage of forecasts that are improved by targeted data –

- Assimilate larger amounts of satellite, remote-sensed, and in-situ observations in target regions - do not rely on intermittent small sets of observations

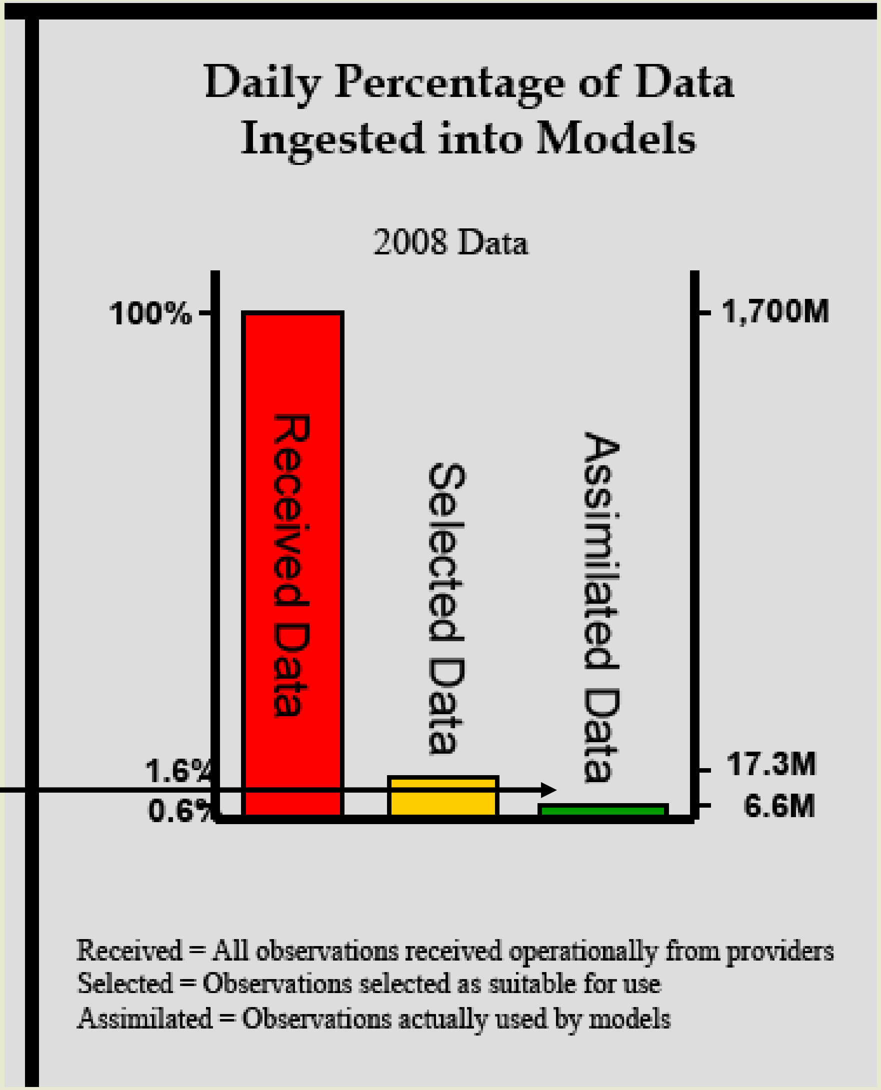
- Improve targeting techniques
- Improve data assimilation procedures

Satellite observations = targeting resource

- Radiances from infrared and microwave sounders on polar orbiters
- Cloud and water vapor motion vectors from geostationary platforms
- Surface winds from space-based scatterometers

LESS THAN 2% OF ATMOSPHERIC OBSERVATIONS ARE ACTUALLY ASSIMILATED FOR OPERATIONAL FORECASTING

- Satellite channel-selection
- Regional variations in satellite observation data-thinning



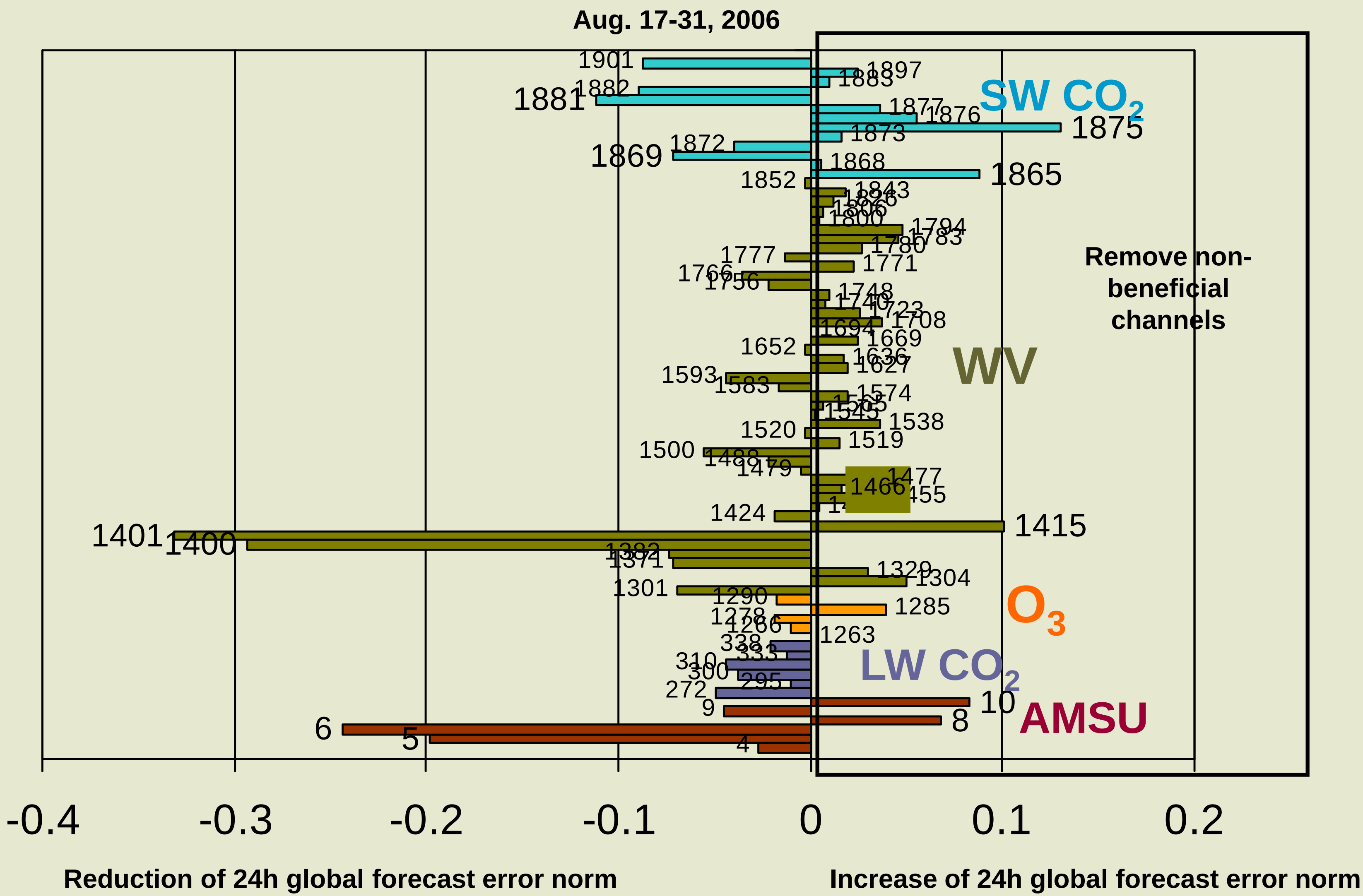
Targeting Strategies –

How much benefit can we obtain by "tuning" the network of existing regular satellite and in-situ observations in a targeted sense?

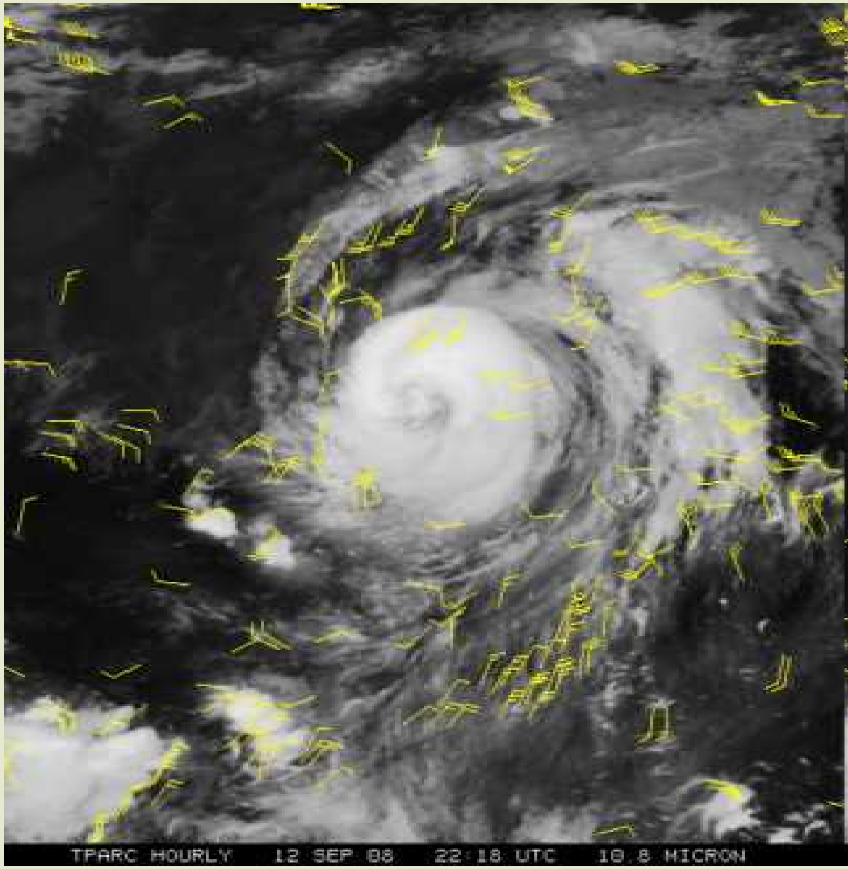
- **Targeted satellite data thinning**
- **Targeted satellite channel selection**
- **On-request feature-track wind data for anticipated high-impact weather events**
- **Increase observations from commercial aircraft in certain regions**
- **Request radiosondes at non-standard times**

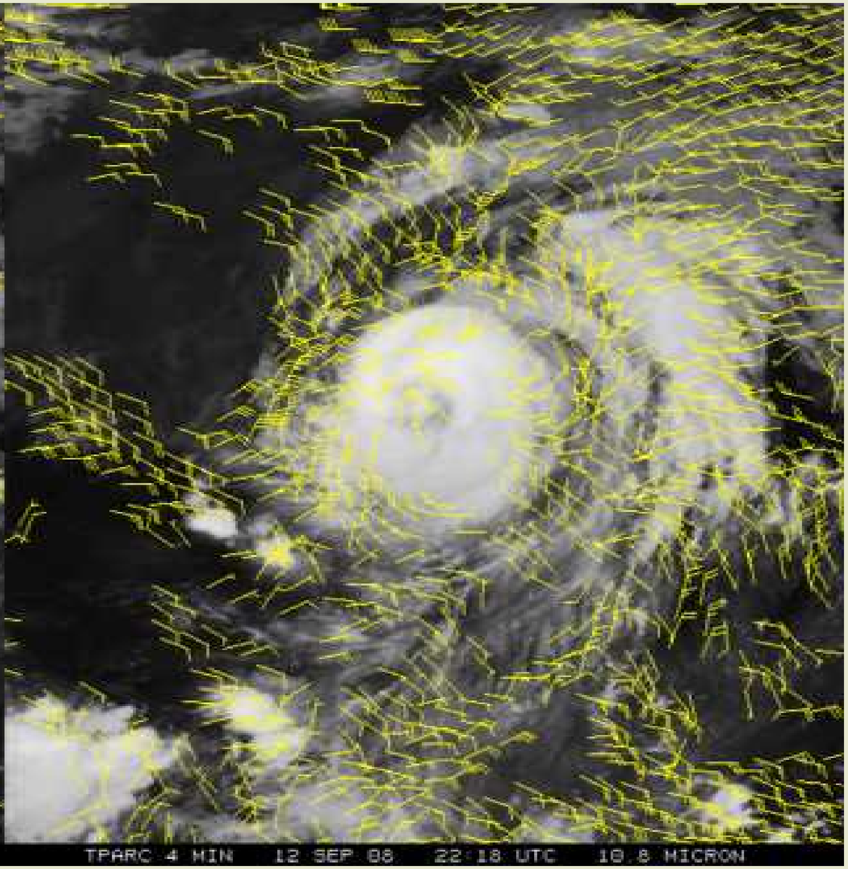
What is the potential benefit from observing larger sections of the targeting subspace, instead of attempting to survey the smaller-scale areas of maximum sensitivity which have been the primary focus of previous field programs?

AIRS channel selection with adjoint-based observation impact



Feature-Track Winds from geostationary satellite

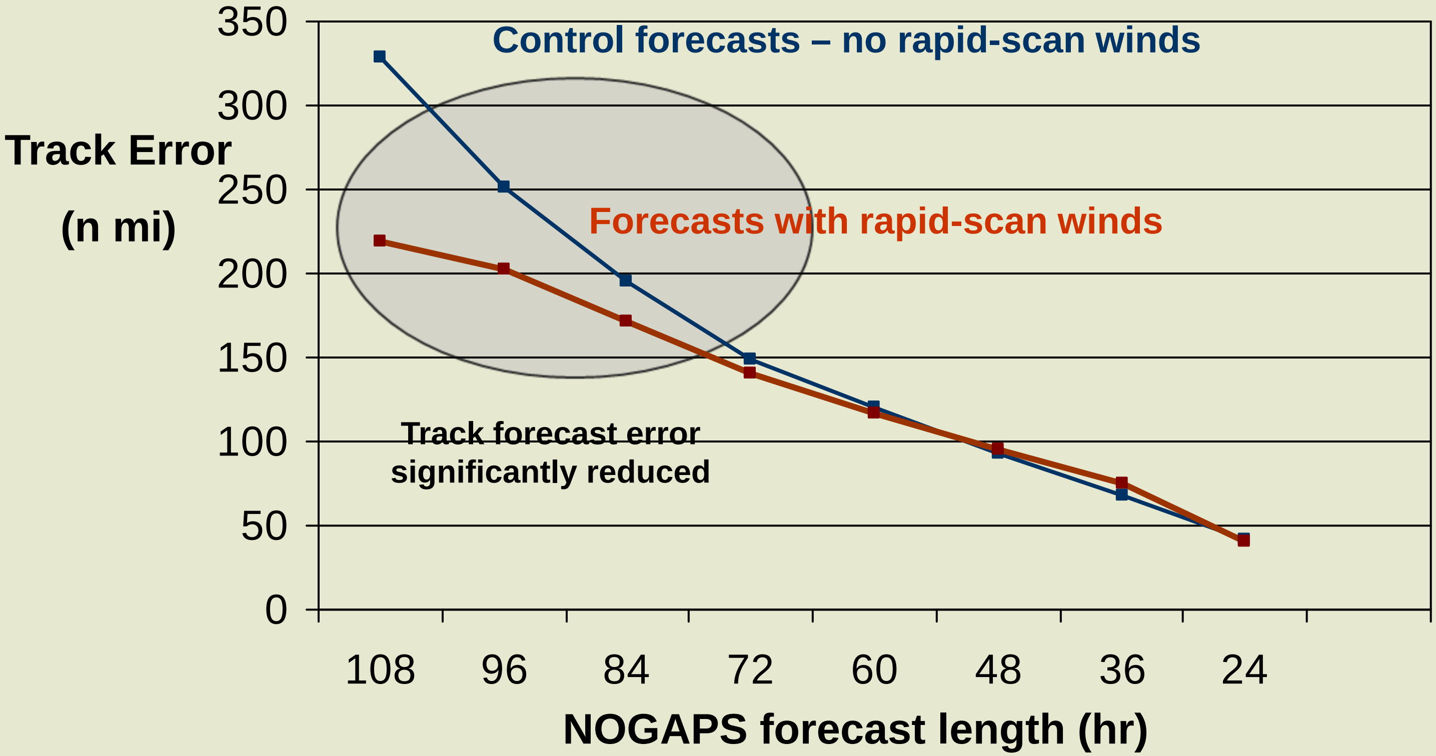




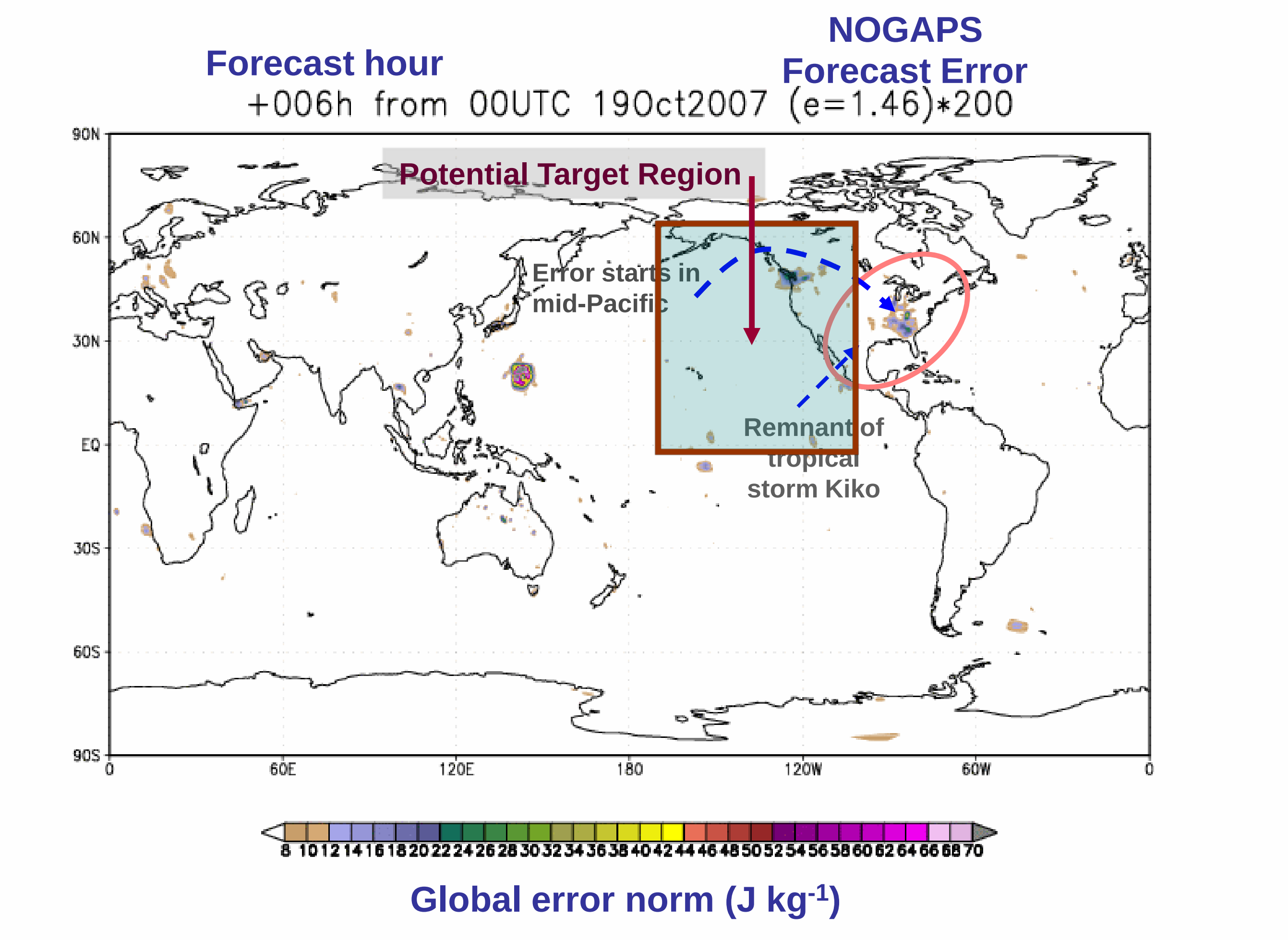
Hourly Scan

4-min Scan (Rapid-Scan)

Improvement of Katrina track forecasts with assimilation of Rapid-Scan wind observations

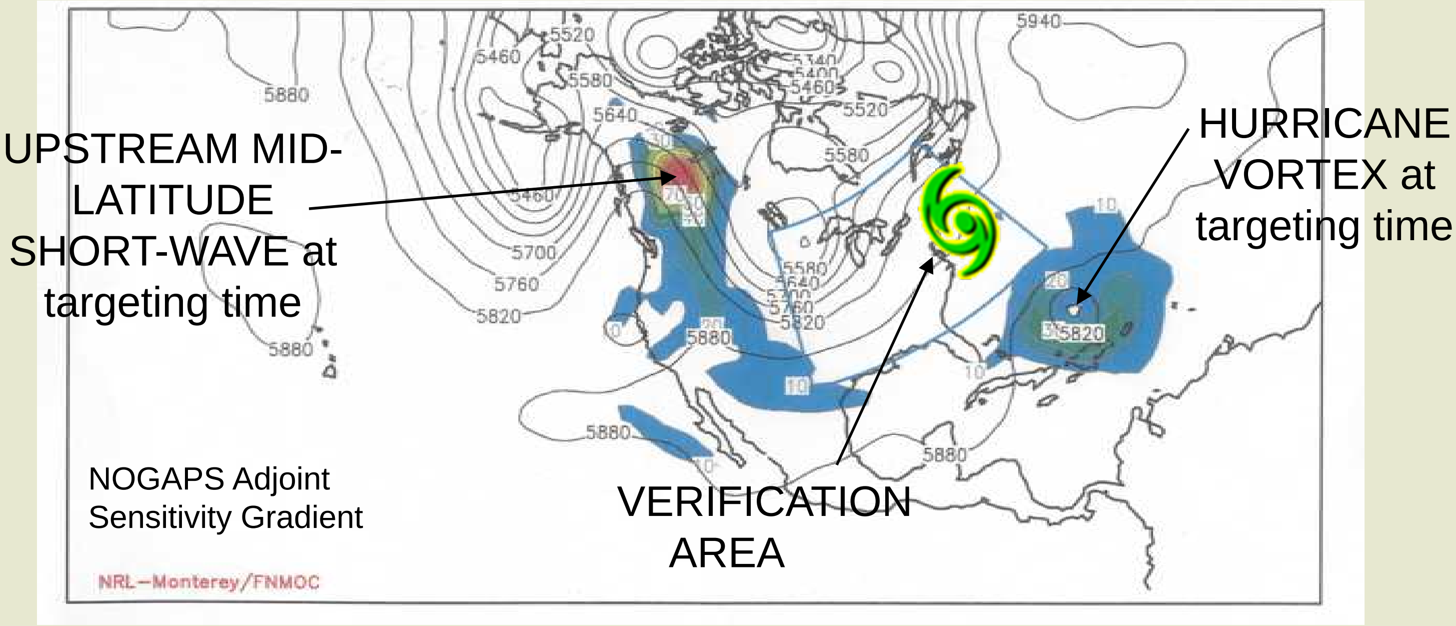


Large error growth in a 5-day forecast



Targeted Observing Example

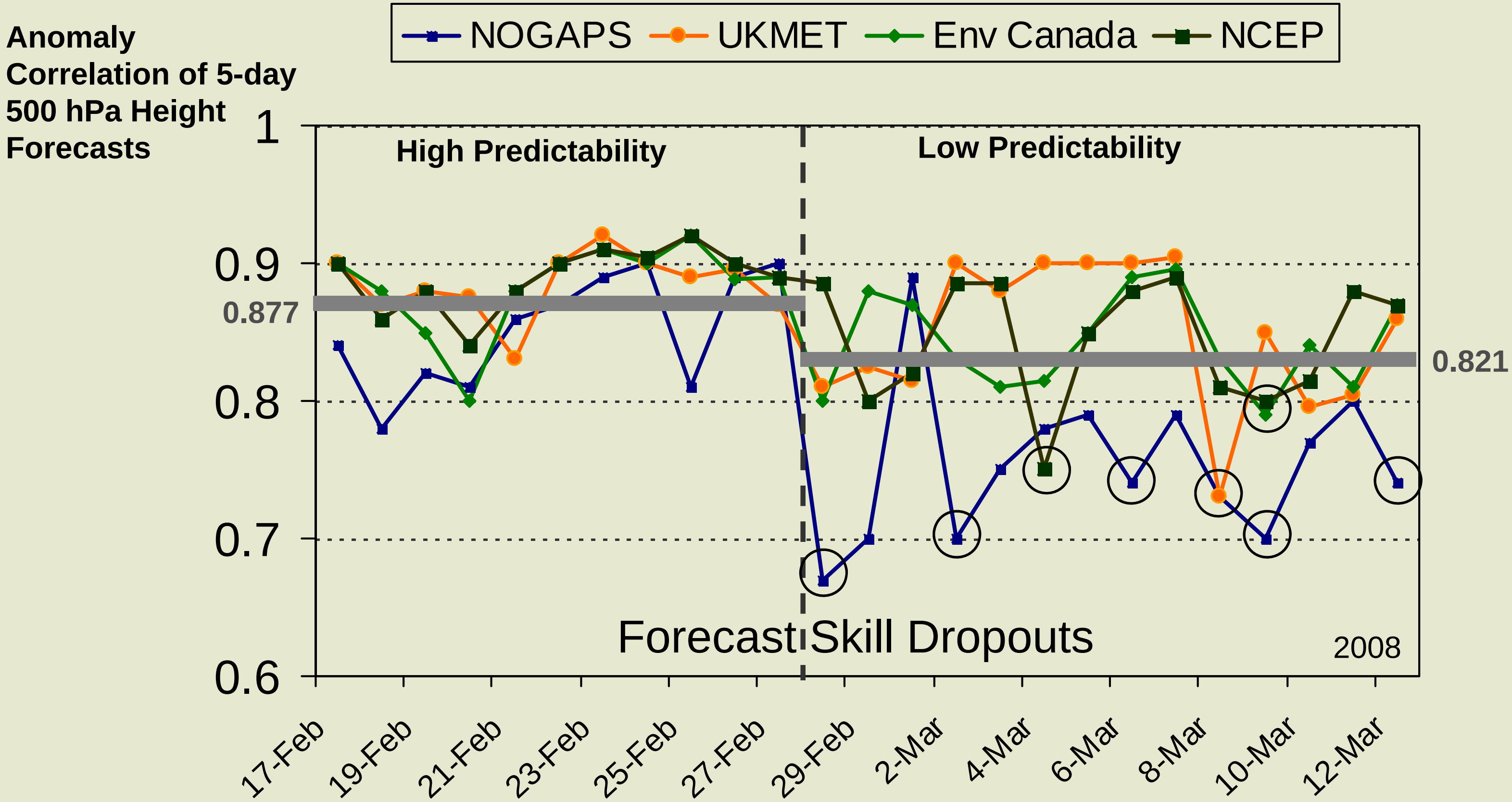
Target Regions for 72h Forecast of Hurricane Floyd



Target: 00UTC 13 Sep 1999

Forecast Verifies: 00UTC 16 Sep 1999

High and low-predictability flow regimes



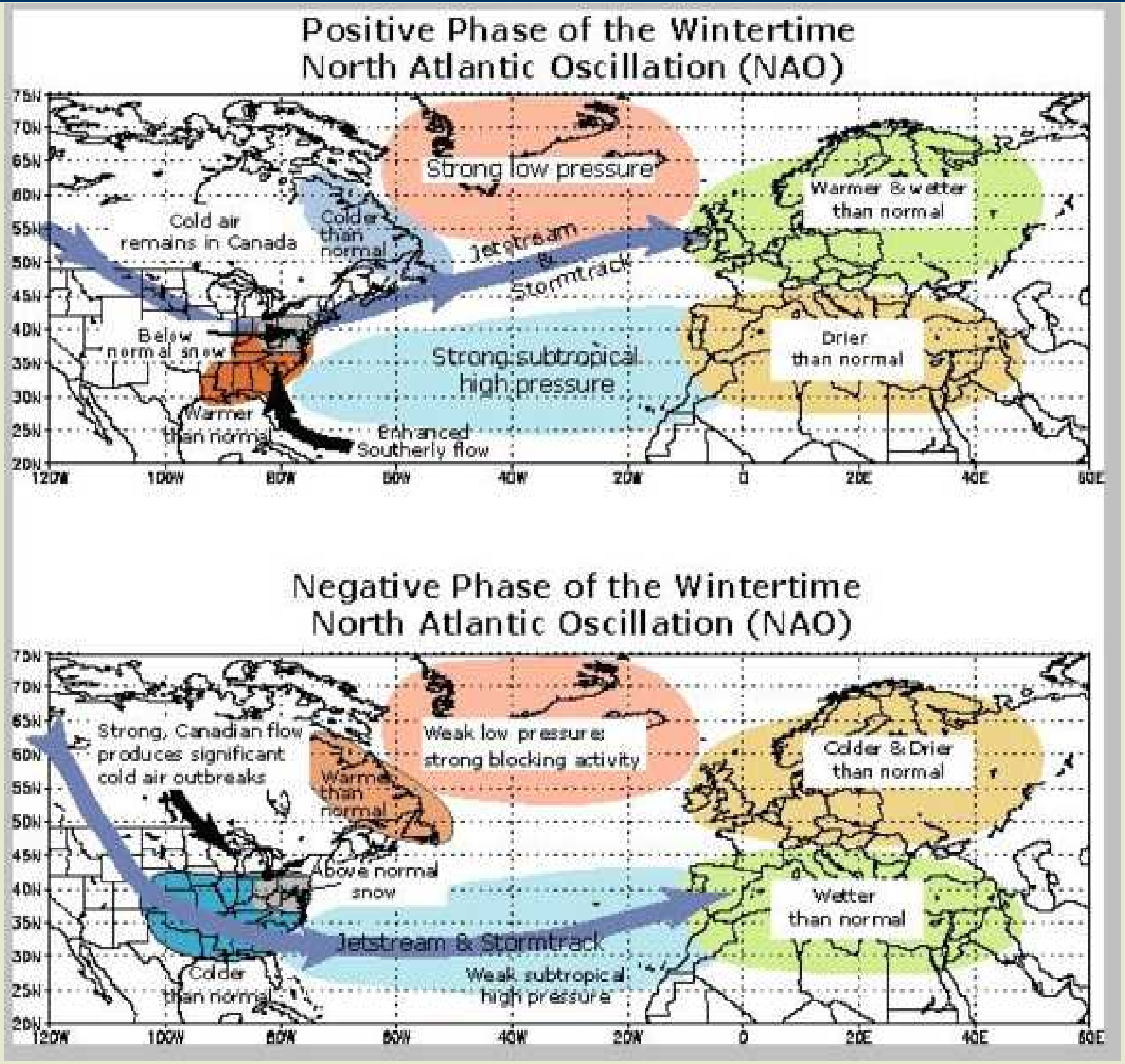
Where does the observing network need to be enhanced during low predictability flow patterns?

NAO Phases

North Atlantic Oscillation

Lower Predictability?

Higher Predictability?



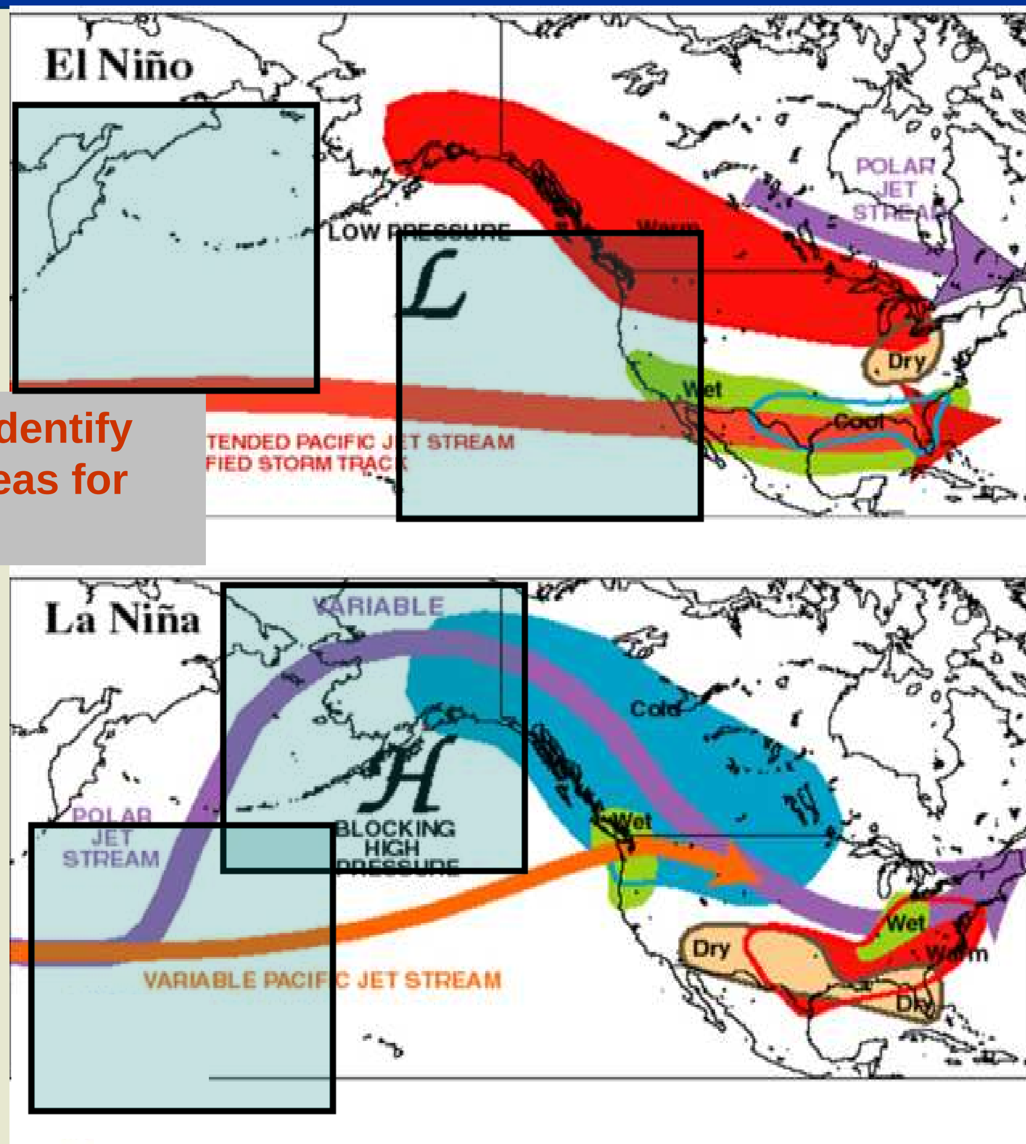
ENSO Phases

El Nino – Southern Oscillation

Higher Predictability

Research Objective: Identify observation target areas for ENSO phases

Lower Predictability

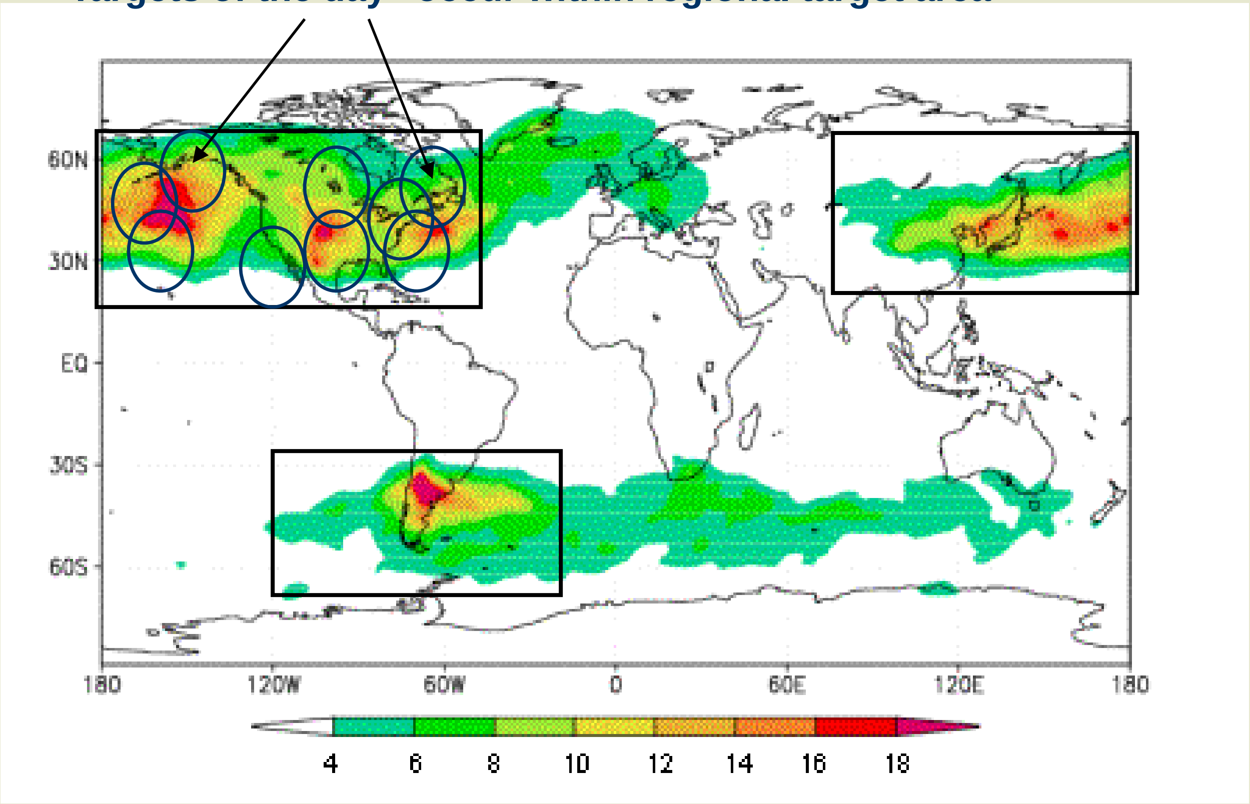


New Concepts of Targeting

Extended-duration (2-4 week) Target Regions

Continuous targeted observing over regional areas during flow regimes that are associated with low-predictability

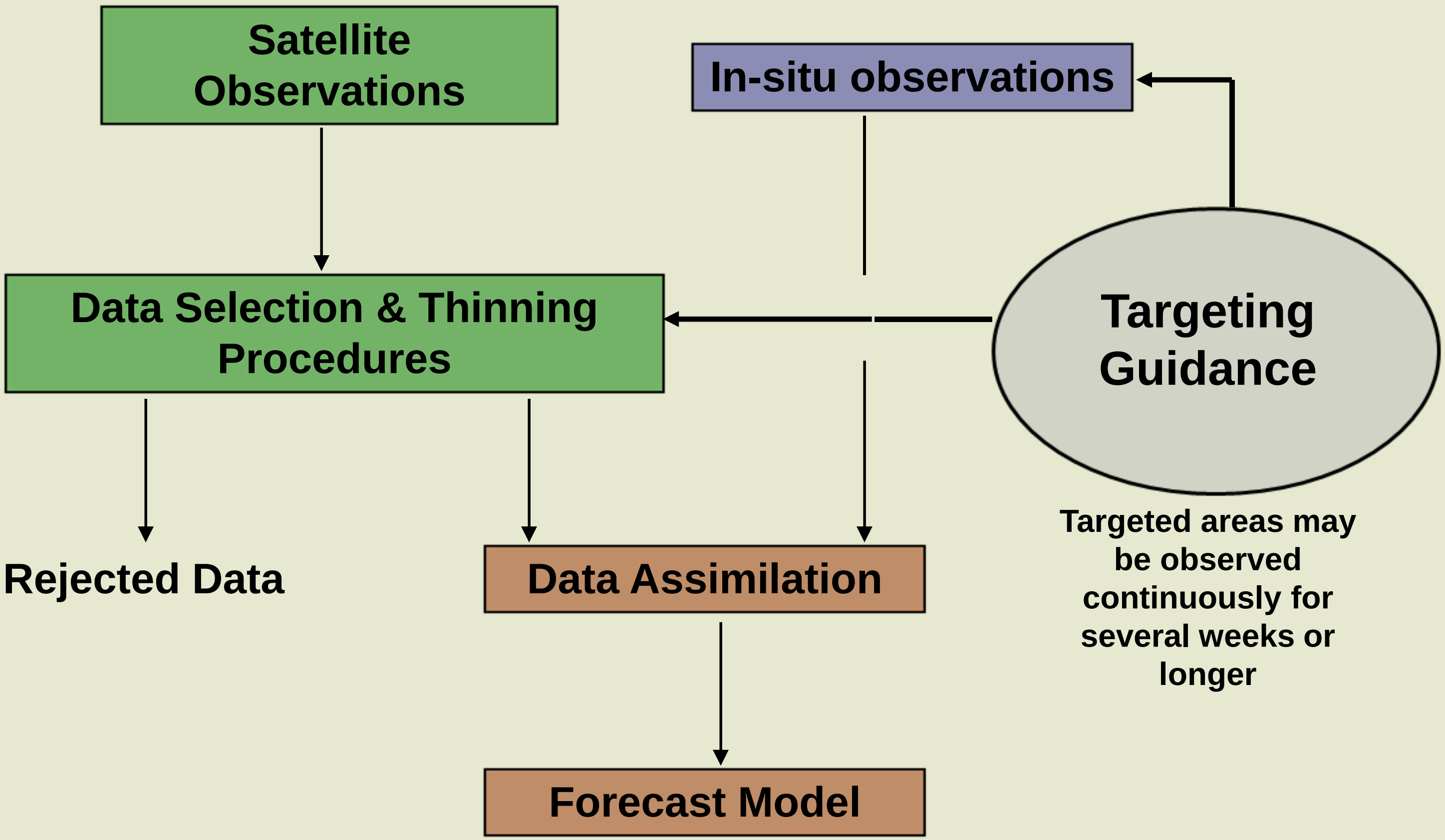
"Targets of the day" occur within regional target area



Time-average sensitivity - Dec 2003 (shaded) - NOGAPS

New Concepts of Targeting

Targeting Strategies



New Targeting Paradigm

1. Identify anticipated low-predictability flow pattern using information from extended range deterministic and ensemble forecasts
2. Define regional target area using sensitivity guidance
3. Begin assimilation of additional observations in target area: continue on hourly or 6-hourly basis through entire life cycle of flow regime

- Added computational cost of regional targeting is minimal - estimate not more than 5-10% increase in total number of assimilated global observations
- We have only partial control over what observations are provided, but total control over which subsets of observations are assimilated

Some conclusions about adaptive observing

- Targeted observing has the potential for significant improvement to deterministic and ensemble forecasting
- Previous targeting field programs have achieved only a small fraction of this potential – intermittent small sets of data (10-50 dropsondes) have modest beneficial impact
- New and next-generation satellite data are a primary resource that can advance the impact of targeting
- In-situ targeted observations provide value in certain situations where satellite observations are insufficient (including cloudy areas)

Predictability and data assimilation research opportunities at NRL-Monterey

- Operational systems development and research programs –
- Adjoints of global model (NOGAPS), regional model (COAMPS) and data assimilation system (NAVDAS)
- 4d-var and ensemble-based data assimilation
- Field program research: THORPEX, TCS-08
- Opportunities for post-doctoral research, and visiting scientists

- Contact: Rolf Langland langland@nrlmry.navy.mil
- Nancy Baker baker@nrlmry.navy.mil
- Carolyn Reynolds reynolds@nrlmry.navy.mil
- Melinda Peng peng@nrlmry.navy.mil - Branch Head

End of Presentation !