VLB ARRAY MEMO No. 237

NATIONAL RADIO ASTRONOMY OBSERVATORY
Edgemont Rd, Charlottesville, VA 22901

7 June, 1983

To: VLBA Design Groups, CLBA Planning Committee, CAS Radio Astronomy Committee

From: A.H.Bridle and R.C.Walker

Subject: A Low-Risk Canada/US VLB Array Option.

We are concerned that the US/Canadian meeting in Charlottesville on April 21 1983 agreed on the high scientific merit of a 14-element VLB Array but could not outline an administrative structure for a collaboration that would be acceptable in both countries. We feel that the opportunity to do better science with a larger array is so attractive that more options for the form of Canada/US cooperation should be explored, even though both countries are presently concentrating on funding their separate arrays. This memo outlines an option for a joint array whose national components are independently viable subarrays which could be managed by separate organizations cooperating for mutual benefit. This option reduces difficulties related to oversight of employees of one organization by the other, and minimises the transfer of funds and personnel between countries. It also provides each country with a partial "safety net" in case of failure of funding in the other, through an array configuration in which 80% of the antennas are in locations specified by the present independent designs. It may be particularly pertinent if the Canadian government is prepared to fund some VLB development, but not at the level of all nine antennas proposed for the CLBA.

THE SCIENTIFIC CASE FOR CANADA/US COOPERATION

The separate US and Canadian VLB array plans will both lead to attractive instruments, but some facts of array design argue that we should still explore cooperative options until one country becomes committed to a particular construction strategy. These facts are:

(a) The number of independent baselines in an array scales almost as the square of the number of antennas. The information gathered in a given time by a 14-element array equals that gathered in the same time by two independent ten-element arrays. As both the VLBA and CLBA design costs are dominated by antenna-based costs, the 14-element array costs only 70% as much as the total of two 10-element arrays. Operating two separate arrays is simply not a cost-effective way for the US and Canada to gather imaging information, because the cross-correlations between the two arrays are lost (except perhaps occasionally in special experiments for which the arrays are scheduled together).

(b) Many astrophysical problems require maps at similar resolutions over a wide frequency range. Much physics can be done by studying the frequency dependence of radio source properties at high, but similar, resolutions from about 1 GHz to several tens of GHz. Neither the VLBA nor the CLBA plans a wide enough range of baselines to have much useful resolution-independent frequency agility. (With the present designs, restricted subarrays, giving poor-quality maps, would be needed to span more than an octave in frequency at fixed resolution). Arrays with a wider range of baseline lengths not only map wider fields of view with given dynamic range (or "fidelity"), but also map the frequency dependence of source properties more accurately. Neither country acting alone can add antennas to extend the baseline range of its array within its present VLB array budget.

(c) The versatility of a VLB array would be transformed if its inner elements are an extension of the VLA, particularly if these inner elements can be operated with the VLA, and the outer elements of the VLA operated as part of the VLB array. This would allow us to match a (u,v) plane filter to the needs of any imaging experiment over baselines ranging from 100 meters to 10,000 kilometers. This cannot be done satisfactorily with only ten antennas, but can with thirteen or more. If Canada places antennas on the longer baselines the US can construct a VLA/VLB interface within its existing budget.

THE ORGANIZATIONAL PROBLEMS

The main questions confronting the joint array option following the Charlottesville meeting appear to us to be:

1. Can one design a joint array in which both the Canadian and US contributions have some useful stand-alone capability, so that there might be scientific reasons for operating them separately from time to time ? (The "n-squared" argument above says that separate operation is undesirable for mapping projects, but this does not apply to astrometry and geodesy with strong point sources. In any case, stand-alone viability has been a stumbling block of the joint array discussion so far).

2. Can a joint project be designed within which either partner can begin construction with a viable "fall-back" option in case the other drops out before the project is completed ? Neither country is yet assured of construction funds, and the time scales for settling this may differ in the two countries. Each is concerned that agreeing to collaborate may delay its own funding, or that a financial emergency in the other could cripple the project.

3. Can a project be done without setting up a new international organization ? Is there a meaningful division of work between all-US and all-Canadian organizations, so that we are not delayed by difficulties in starting a new organization and in establishing its relations with Canadian and US funding agencies ?

We have examined a plan for a joint array configuration which could solve some of these problems.

A SOLUTION IN CONFIGURATION SPACE

The stand-alone capability for the US in a JOINT project stems from the fact that the VLA is in the US far from the Canadian border. An interface to the VLA should be built and operated within the US contribution. The interaction between the VLA and the inner parts of the VLB array can be managed most easily if both are handled by NRAO. Geography also makes Canadian stations supply mainly >1000 km baselines to any joint array. A way to achieve "stand-alone" viability is for Canada to provide as many long baselines as possible.

We therefore propose that the Canadian part of a joint array be (a) four of the CLBA sites and (b) one or both "offshore" stations considered for the VLBA -- "Hawaii" and/or the Caribbean antenna (termed "Arecibo" in the VLBA plan, though it need not be in Puerto Rico for good u,v coverage). The Canadian subarray would be a five or six-station array with good stand-alone performance for high resolution work. It would be well suited to astrometry, geodesy, etc., or for mapping small fields. We propose that the US part be based on the chosen VLBA configuration (M83), forming a ten or nine-station array with an excellent interface to the VLA. Its stand-alone coverage would be similar to that of the VLBA, reduced in scale to a longest baseline of 2000 km. It would be excellent for all experiments except those requiring the highest resolution. (Its stand-alone role would be analogous to the B and C arrays of the VLA, the joint array being used to obtain the analog of the A array).

A combined 15-element array would give reasonable coverage without being strictly optimized in the (u,v) plane. Optimization requires that joint configuration and project management be agreed to very quickly. This became a difficulty at the Charlottesville meeting. It may be politically optimal if both countries retain an option to proceed independently until construction funding schedules become clear in both countries. For illustrative purposes, we therefore consider a configuration with 4 sites from the (P10G4) CLBA, and 7 from the (M83) VLBA. Table 1 lists the configuration, and Figure 1 shows its geographical layout. Figures 2-7 compare its coverage on different scales with those of the CLBA and VLBA. Figure 8 illustrates the coverage of the "US sub-array" alone, and Figure 9 that of the "Canadian sub-array" alone. This configuration offers a solution to problem (1) above.

Our only concession to optimization of this array was moving the Iowa site in the M83 array to Topeka. This improves the coverage of the US sub-array as a stand-alone configuration without much deterioration in the larger-scale coverage. If it quickly became clear that both countries will commit construction funds and wish to cooperate, the coverage could be improved (and possibly an antenna removed) by optimisation.

The proposed array also offers a solution to problem (2). If funding is insecure in one country when the other is ready to start, two strategies can be adopted.

1. If the US starts first, it can commit to building the VLBA sites at VLAE3 (Winston, NM), Bernal NM, Fort Davis, Kitt Peak and Owens Valley first, deciding about the ones closest to the Canadian border, or offshore, later. The plans become locked in by the decision to build at Iowa (versus Topeka) and by the decision to build either or both of the offshore sites. A collaboration with Canada would remain sensible until the Oroville, WA or Massachusetts (Haystack ?) sites were begun. Once the last three US sites were started, one could not build the VLAE4 (Pie Town, NM), VLAE5 (Bernardo, NM) or Roswell, NM sites within the same budget.

2. If Canada started first, the CLBA sites at Penticton, Algonquin, Yellowknife and in Newfoundland could be built whether or not the US partnership was in place. The plans are locked in by the decision to build either offshore site, or to proceed with the rest of the all- Canadian CLBA. Funding levels for these options would not be the same, however, so this choice might not be as easy to exercise as that described above.

OTHER CONSIDERATIONS

The Canadian and US designs specify different antenna sizes and surface accuracies. The CLBA chose a 32-m antenna based on budgetary estimates from a supplier of 32-m and 25-m antennas. The larger aperture appeared cost-effective relative to higher surface accuracy, but the scaling laws for antenna size and surface accuracy in these estimates were unusual. We should examine the choice with budgetary estimates closer to the actual start of construction. Possibly if the Canadian and US groups review the same sets of numbers we may draw the same conclusion. The configuration described above leaves open a useful option. If panels usable to 43 GHz can be fabricated at costs little higher than those of panels usable to 22 GHz (and such panels are acceptable to the manufacturer of 32-m antennas) we could equip the "Canadian" sites with 32-m class antennas. This is justifiable because they provide baselines on which the sources would be weakest. The penalties of having two sizes of antenna (not necessarily different feed geometries, etc.) in the joint array are mainly those of additional design effort. They would be small at the operational stage due to the small fields of view being mapped. The CLBA plans a smaller antenna at Yellowknife; perhaps this could be identical to the elements in the "American" array ?

The VLBA specifies more receivers than the CLBA. The cost per site of the electronics in the "Canadian" subarray is increased if the US specifications remain. This may be acceptable if only five or six sites have to be outfitted with Canadian funds instead of nine. Some items which are more expensive in the CLBA plan (e.g. feed fabrication) could be at least partly supplied by the US organization, to offset more frequencies having to be outfitted.

Technical specifications would need to be standardized. But it should not be necessary for all equipment to be identical provided specifications were met. There may be significant flexibility for US suppliers to be preferred in the US operation, Canadian in the Canadian, etc. It may however be more efficient to build all of one frequency's receivers in one country.

Each country wishes to have a correlation and processing center (or centre !). The planned VLBA correlator could handle the continuum data from the combined array; one correlator with this capacity or greater should still be built. If this is done by Caltech under the current NRAO/CIT memorandum of understanding, further correlator/processor development and construction in Canada will add extra capacity to the mutual system. This could reduce the need for very high duty cycles in the US correlator. Many users might be closer to the correlator/processor in the other country than to the one in their own. Having two processing centers might then be advantageous. We might also consider building one huge correlator across the Canada/US border - but this does not seem necessary.

The array operations center does not benefit clearly from duplication. For the operations staff to remain in good contact with maintenance and array performance evaluation, it is desirable for operations, correlation and processing to be colocated in each country. Otherwise operations standards may slip as the novelty (and difficulty) of running the array wears off; slippage will be minimized if operations staff communicate well with people using the array data. The array needs good dedicated communications from the control center to each antenna, so there may be no added risk in having a control center in each country if this is necessary for political reasons.

ADVANTAGES OF THIS PROPOSAL

1. It provides options for a more substantial Canadian presence in the joint array than has hitherto been considered. (A 4-antenna contribution was considered too small because it lacked stand-alone capability). Either a five or a six-antenna subarray could be negotiated, according to budgetary constraints in Canada.

2. Each subarray has a significant stand-alone capability. This could be an advantage politically in the sense that each country could meaningfully operate its subarray independently for some fraction of the time.

3. It provides an option for larger antennas on the longest baselines, where the increased antenna size is most needed for signal to noise reasons.

4. It provides a management option wherein Canadian-hired personnel can live and work in Canada, US-hired personnel can live and work in the US. The joint project need not become entangled in differing labor practises, tax laws, etc., in the two countries. Some short-term interchanges of personnel between the two countries would be essential for communications. Some coordinating committees would have representatives from both countries, but the daily business, and the funding channels, could be tidily within each country.

5. Each country can retain a "bail-out" option for a while in the event of financial emergency, or slowness getting started, in the other.

6. The Canadian geodetic interests are satisfied within the Canadian subarray. The offshore sites are in fact the ones from the VLBA that are most interesting for geodesy.

DISADVANTAGES

1. This mode of operation ensures the existence of two subcenters of array operation and management. Communications problems could arise which might not within a single organization in one building. Effort would be needed to keep these communications problems at a manageable level. Dedicated phone links, networked computer facilities, and short-term personnel exchanges might all be needed. It will clearly be in the very best interests of both organizations in this joint venture to cooperate as fully as possible with the other. The two-headed administrative structure may be unwieldy, but there will be a common goal and common scientific profit to spur cooperation.

2. The US subarray does not have full-resolution capacity. This is a price to be paid for the fact that the scientific potential of the joint array is much greater than that of the VLBA as presently designed.

3. The mean distance between Canadian-operated sites is increased over the CLBA alone, and at least one is not on Canadian soil. This is again a price to be paid for increased capability of the joint array.

4. The Canadian headquarters could not be both near an antenna and located in Alberta. Some decision as to which of these constraints was more important would have to be made.

RELEVANCE TO FUNDING DEVELOPMENTS IN CANADA

This proposal will be most relevant if it becomes clear that the full nine-element CLBA will not be funded soon. It will not be a preferred option as it stands if a nine-antenna budget is available in Canada. The VLA/VLB interface and the Canada/US cross-correlations are so valuable that we should however consider (a) small adjustments to the separately optimised arrays, and (b) agreements between independent organizations to extract the cross-correlations regularly, whatever number of new antennas the two countries build in the 1980s. Note that a 19-element array gathers more than twice the information obtained with separate nine and ten-element arrays in the same time, at almost the same cost !

Table 1
STATION COORDINATES

The station names, latitudes and longitudes of the sites used in the attached figures are given below. It is assumed that four VLA stations are used with the arrays plotted on 1000, 500 and 200 km maximum scales, i.e. that four VLA antennas are equipped separately as VLB stations and are used with whichever array is being displayed.

CLBA
P10G4 config plus Yellowknife

P10G4-1	48.30	54.11
P10G4-2B	45.95	78.08
P10G4-3	48.88	91.60
P10G4-4	49.07	103.81
P10G4-5	49.15	108.82
P10G4-6	49.19	110.21
P10G4-7	49.24	112.28
P10G4-8	49.32	119.65
YELKNF	62.70	114.50

P10G4-2B is a new antenna at ARO
P10G4-8 is a new antenna at DRAO

VLBA
Final M83 config (VLBA Memo 205)

VLAE3	33.30	107.70
BERNAL	35.40	105.30
KITT	31.96	111.60
FDVSNEW	30.47	103.95
OVRO	37.05	118.28
IOWA	41.58	91.57
MAUI	20.75	156.20
ARECIBO	18.34	66.75
HSTK	42.43	71.49
OROVILE	48.90	119.75

"Low-risk" joint config
Part of P10G4 + part of M83
Topeka replaces Iowa

VLAE3	33.30	107.70
VLAE4	34.30	108.30
VLAE5	34.38	106.95
BERNAL	35.40	105.30
ROSWELL	33.40	104.55
KITT	31.96	111.60
OVRO	37.05	118.28
TOPEKA	39.00	95.70
FDVSNEW	30.47	103.95
ARECIBO	18.34	66.75
MAUI	20.75	156.20
YELKNF	62.70	114.50
PENT	49.30	119.60
ARO	45.95	78.07
P10G4-1	48.30	54.11

VLA stations

AN9	34.24	107.63
AW9	33.97	107.81
AE9	34.00	107.41
AW3	34.06	107.64

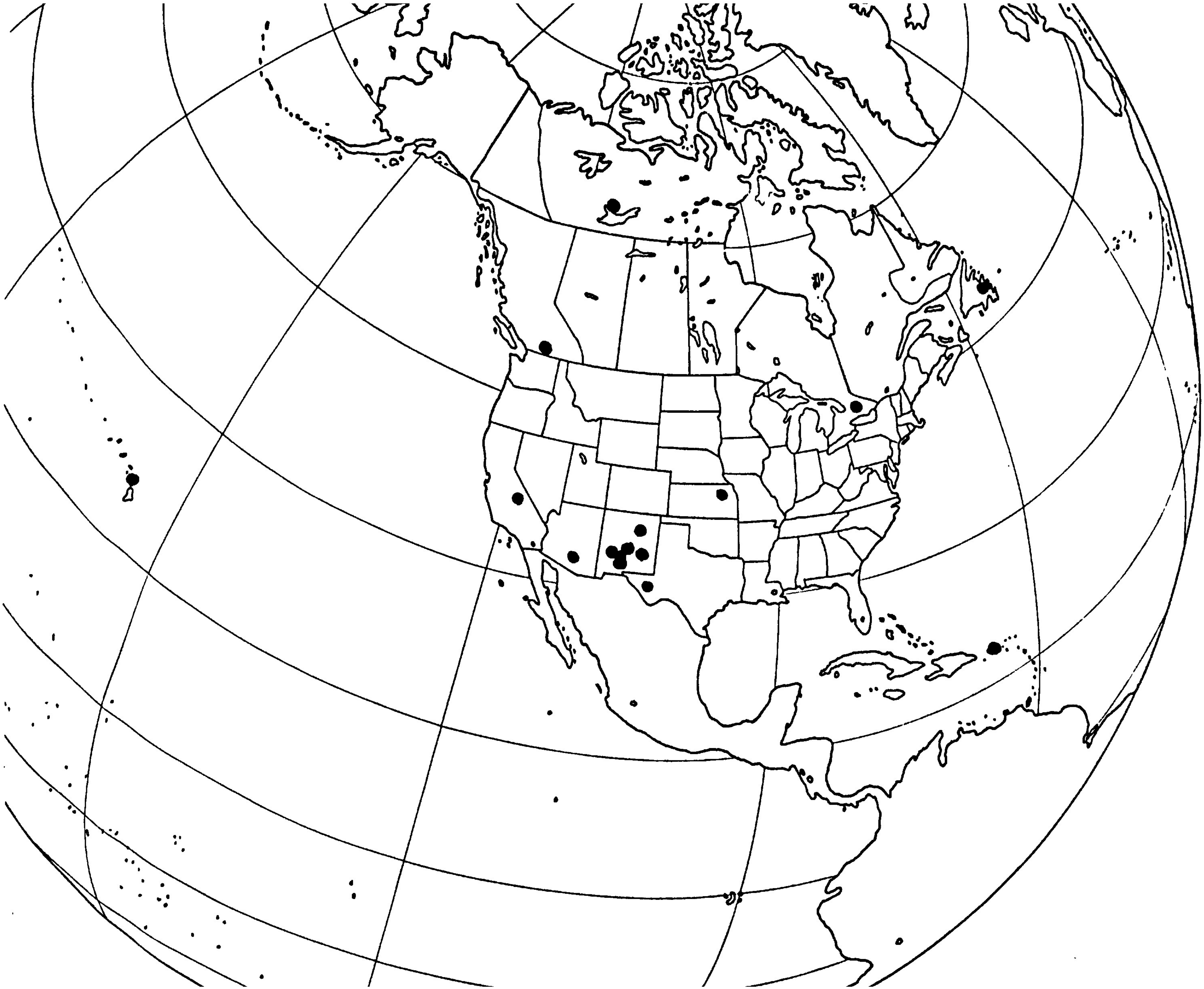
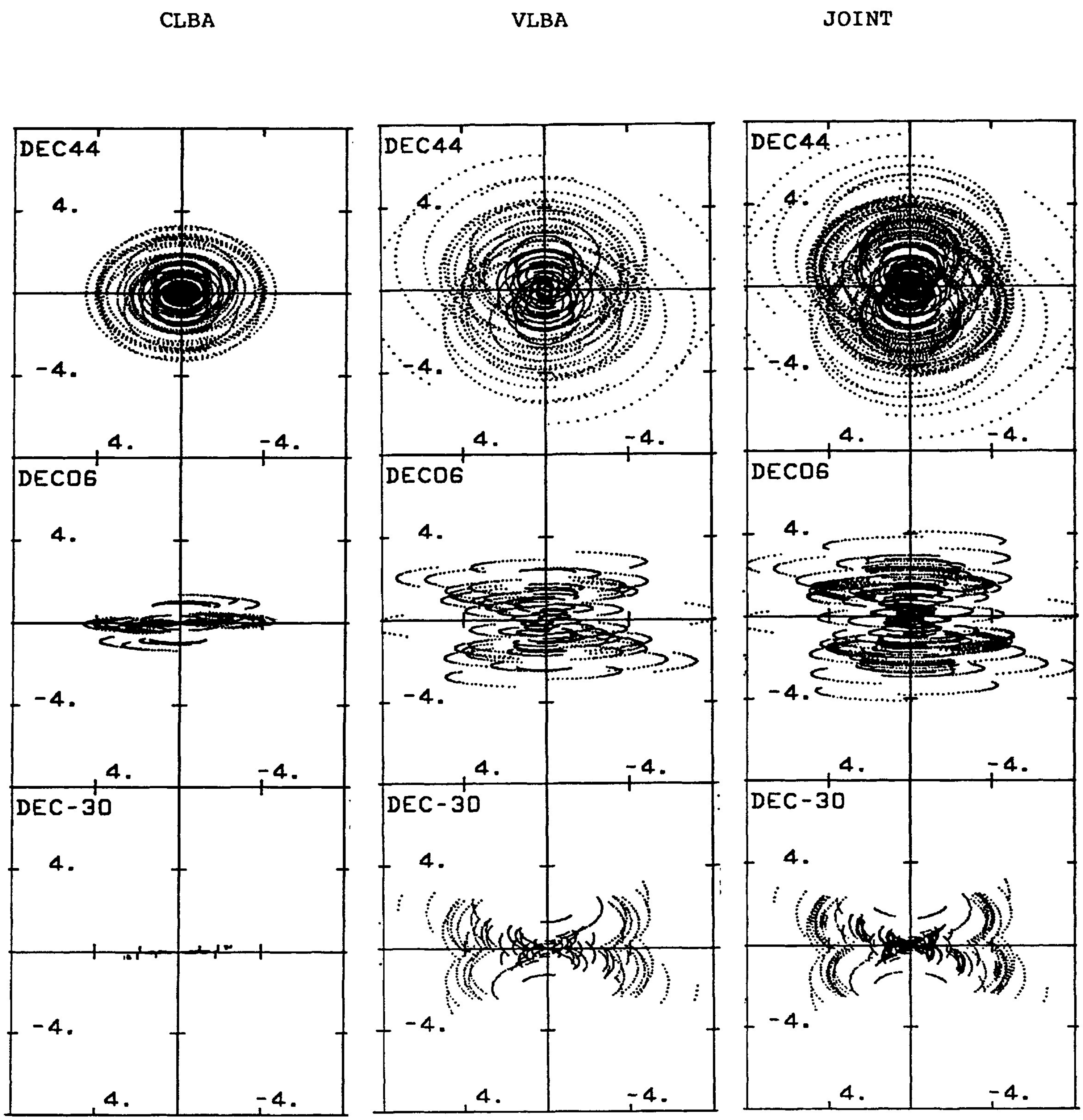


Figure 1 - STATION MAP

Figure 2

Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 8000 km.

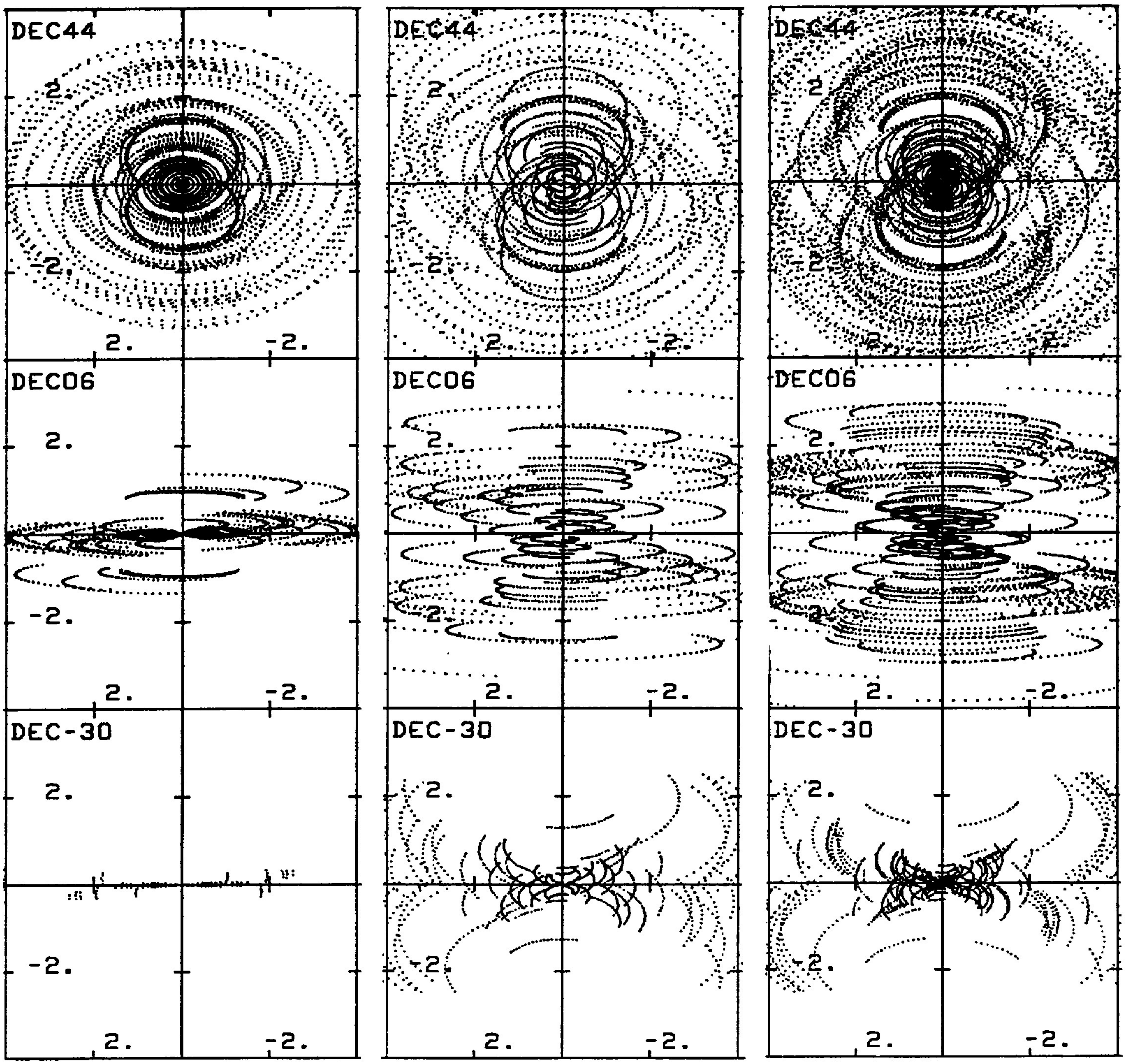


Scale in km
(kilometers x 10^3)

Figure 3

Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 4000 km.

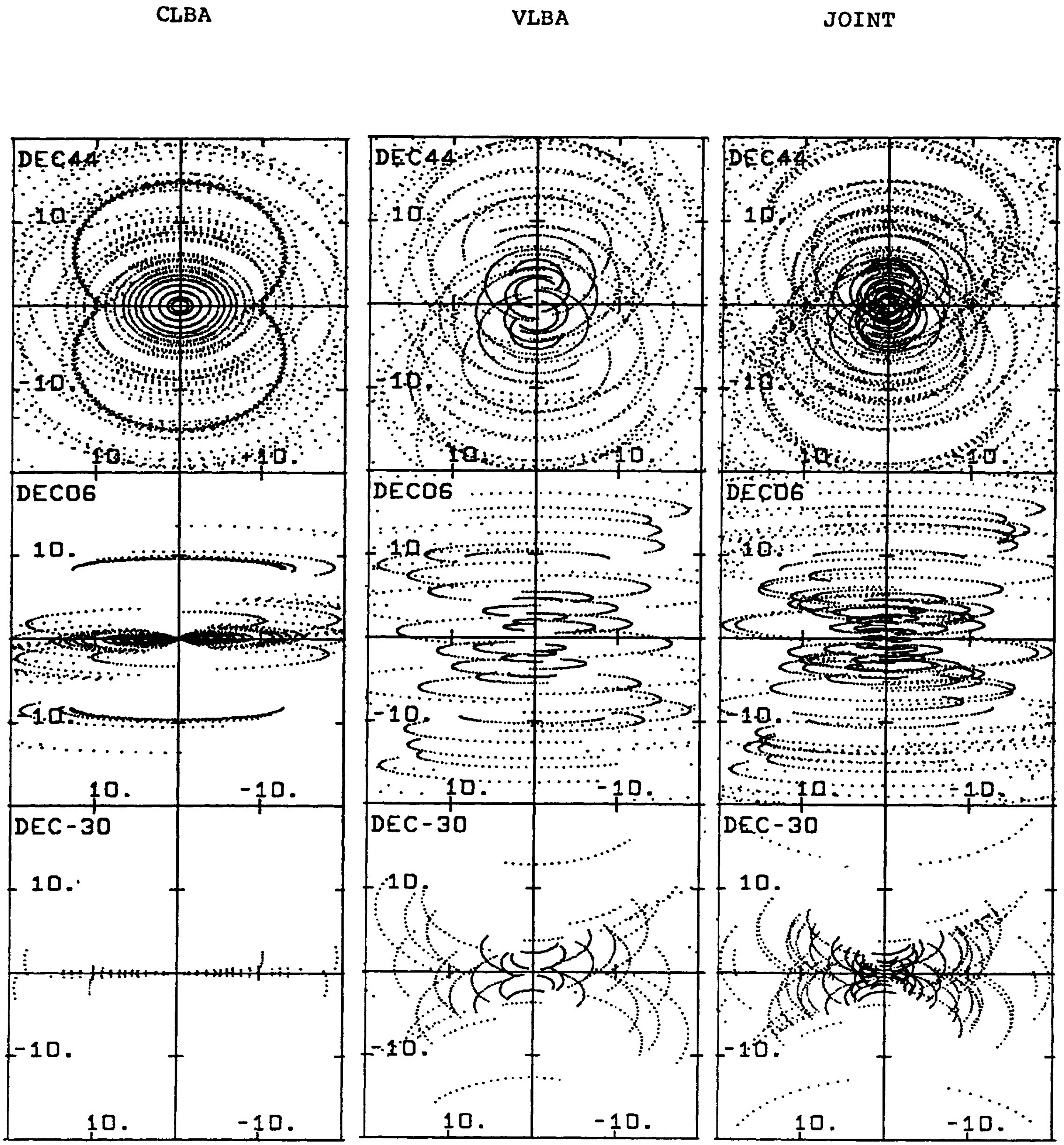
CLBA VLBA JOINT



Scale in km
(kilometers x 10^3)

Figure 4

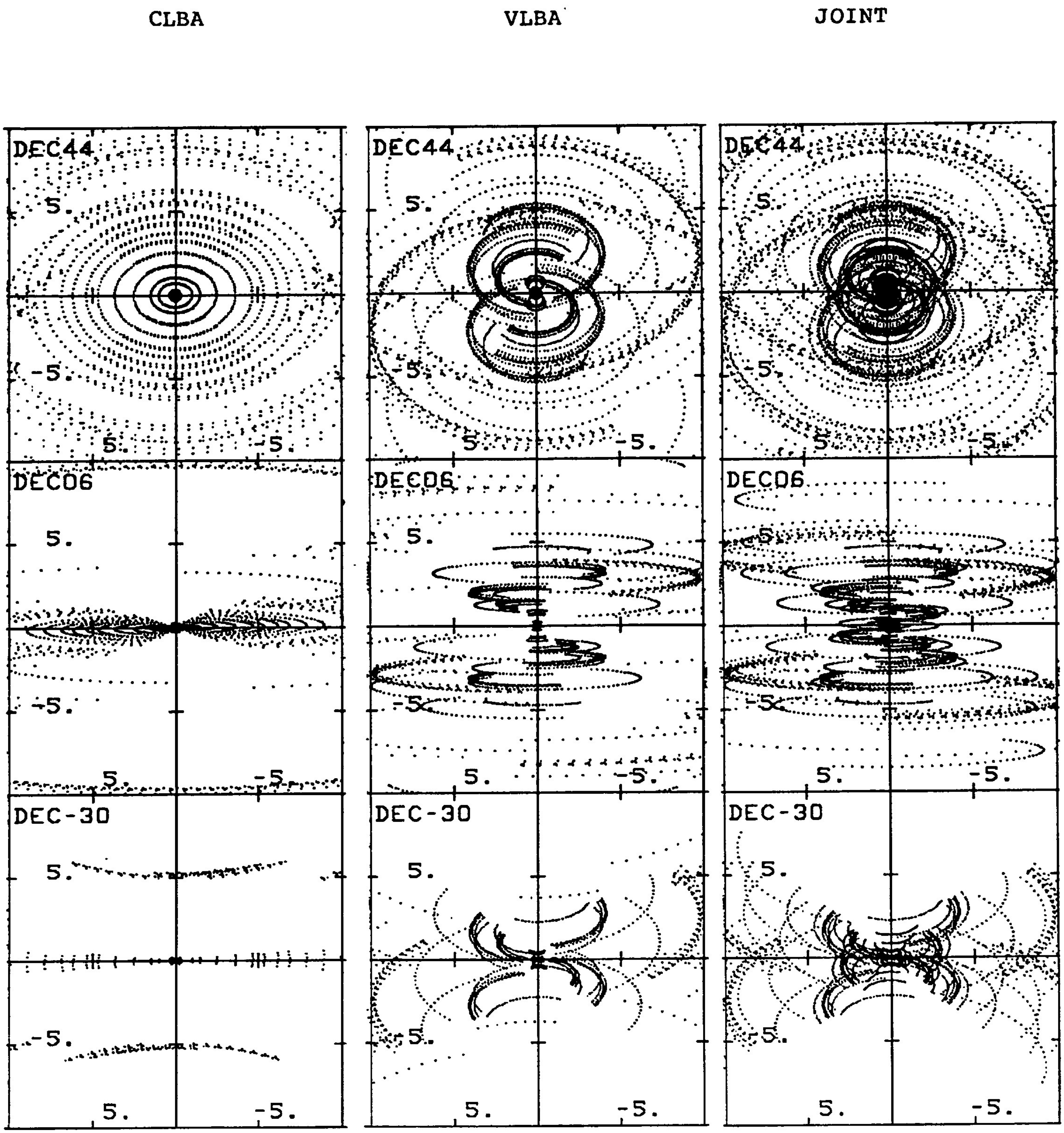
Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 2000 km.



Scale in km
(kilometers x 10^2)

Figure 5

Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 1000 km.
N.B. four VLA antennas are assumed in each of these arrays



Scale in km
(kilometers x 10^2)

Figure 6

Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 500 km.
N.B. four VLA antennas are assumed in each of these arrays

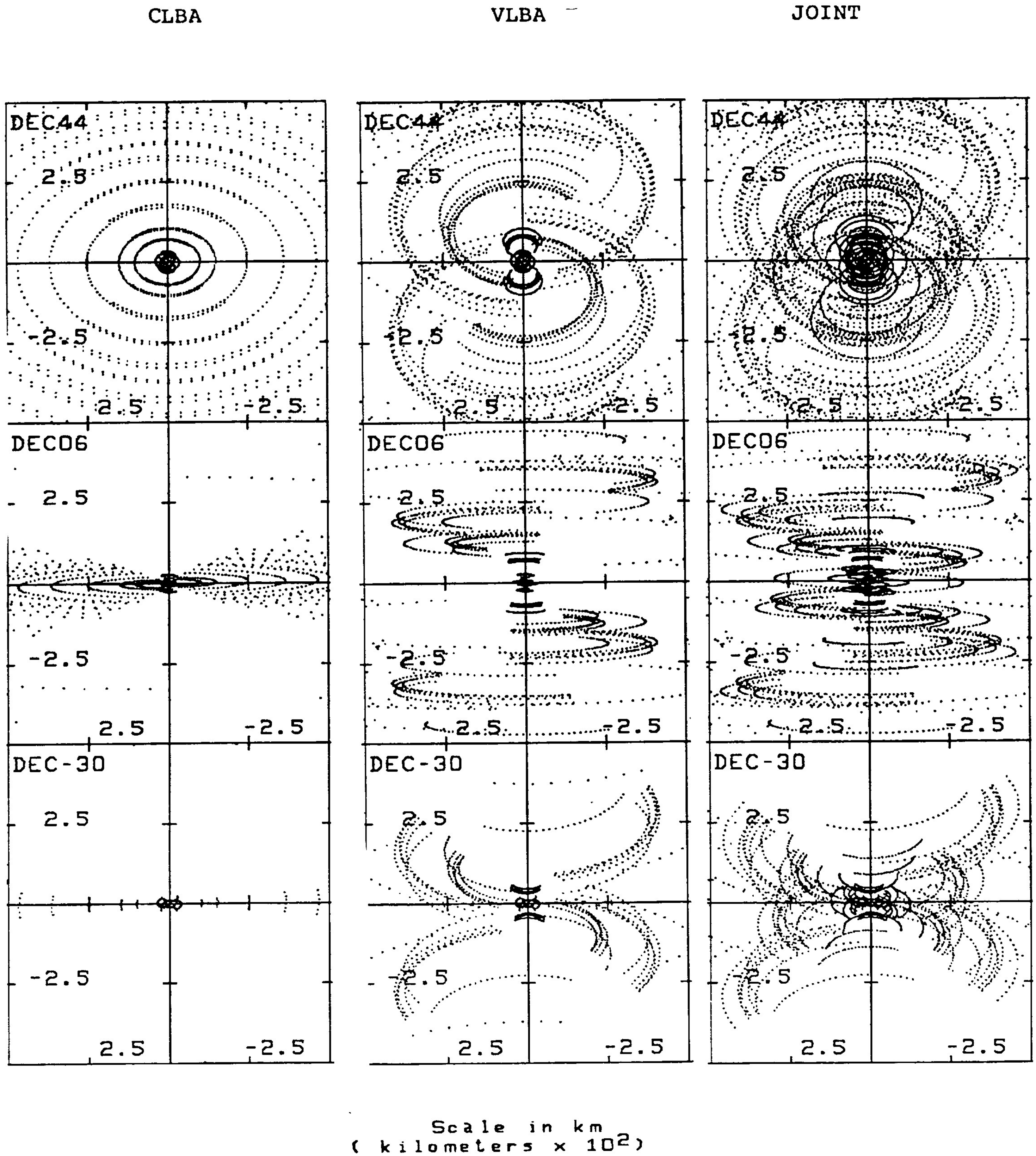
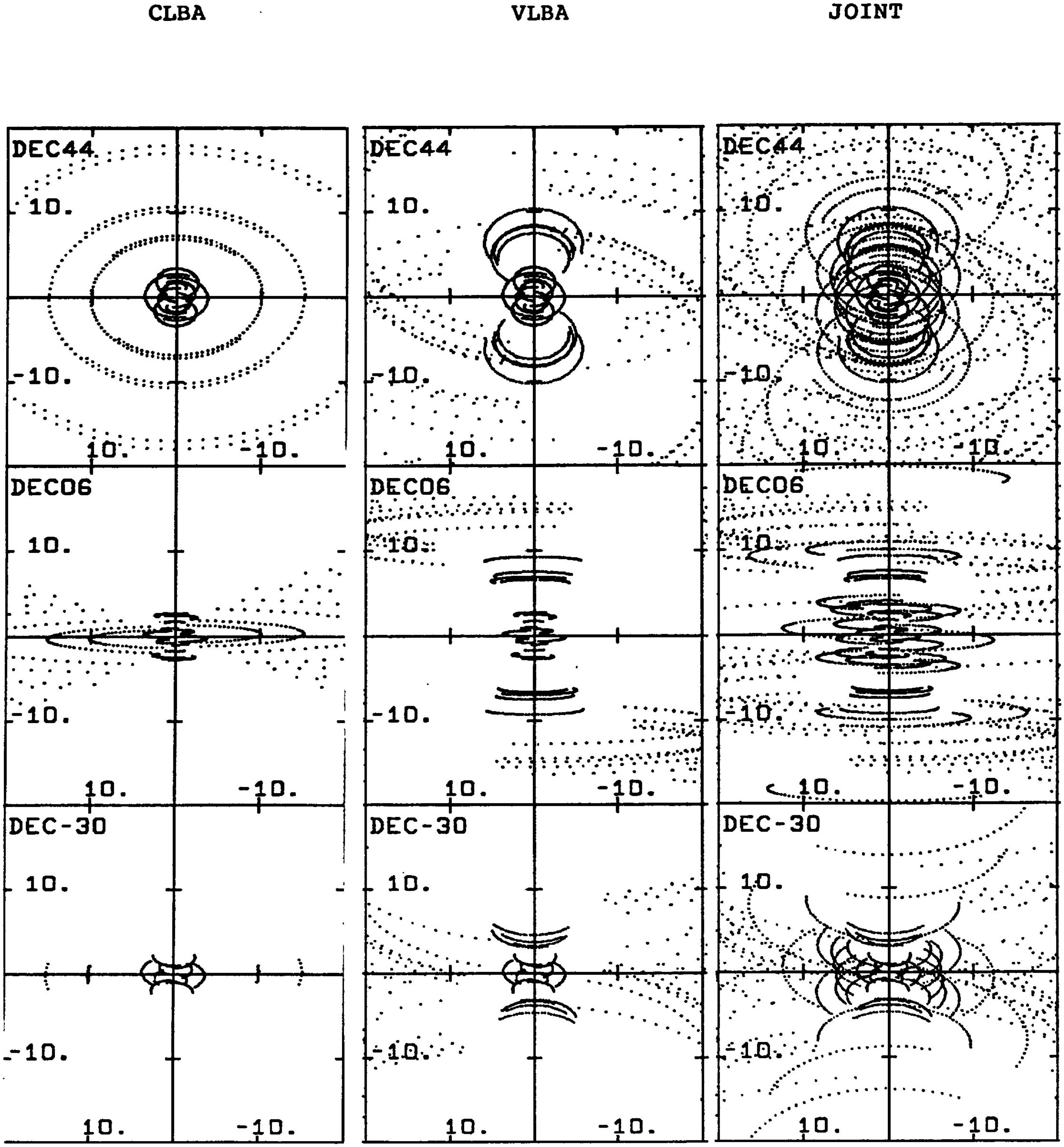


Figure 7

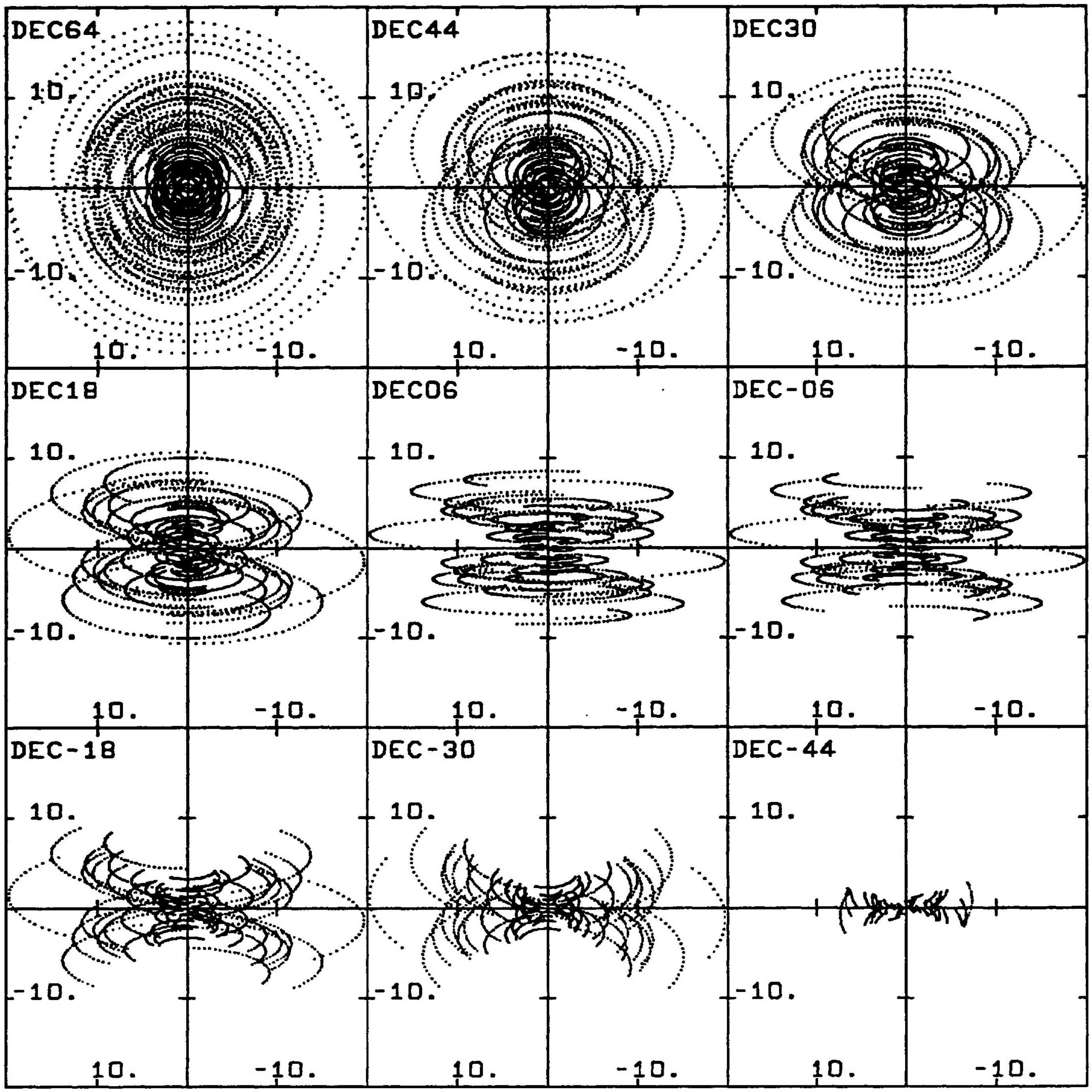
Comparison of CLBA, VLBA and a Joint Configuration with a maximum scale of 200 km.
N.B. four VLA antennas are assumed in each of these arrays



Scale in km
(kilometers x 10^1)

Figure 8

u,v coverage of the "US subarray" operated alone with a maximum scale of 2000 km.

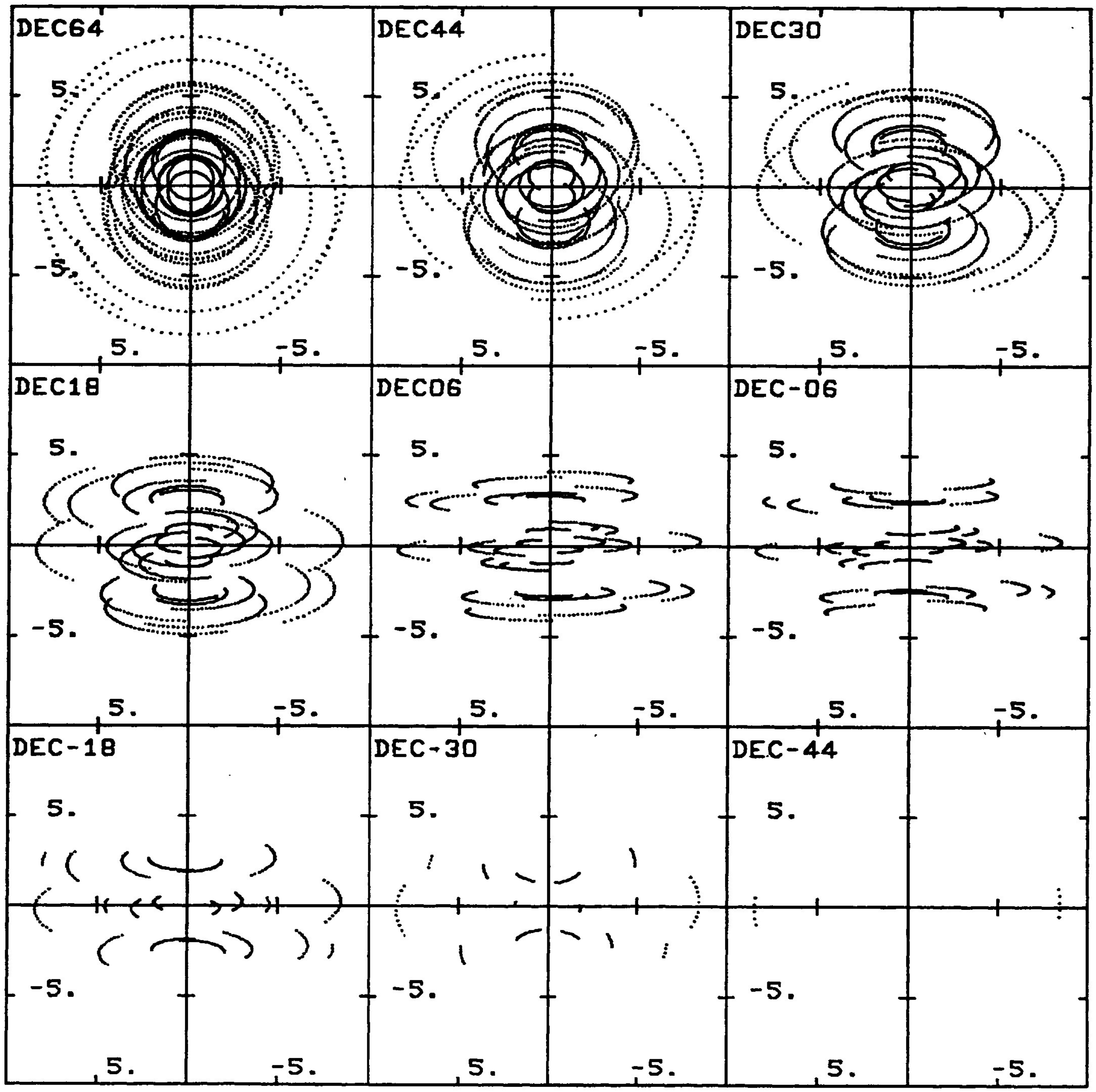


Scale in km
(kilometers x 10^2)

OVRO	37.05	118.28
FDVSNEW	30.47	103.95
KITT	31.96	111.60
BERNAL	35.40	105.30
ROSWELL	33.40	104.55
VLAE3	33.30	107.70
VLAE4	34.30	108.30
VLAE5	34.38	106.95
TOPEKA	39.00	95.70

Figure 9

u,v coverage of the "Canadian subarray" operated alone with a maximum scale of 10,000 km.



Scale in km
(kilometers x 10^3)

MAUI	20.75	156.20
PENT	49.30	119.60
YELKNF	62.70	114.50
ARO	45.95	78.07
P10G4-1	48.30	54.11
ARECIBO	18.34	66.75

STUDENT LECTURE SERIES 1983 Rev: 06/07/83

All lectures are in the NRAO Edgemont Road Conference Room at 1:00 P.M. unless otherwise noted.

Date		Title	Lecturer
June	13	Introduction	
	15	Radiative Transfer	Jay Lockman
	17	Radio Astronomy Systems	Jay Lockman (at 3 P.M.)
	20	Radio Telescopes	John Findlay
	22	Receivers	Sandy Weinreb
	24	Tour of the Green Bank Site	Fred Crews & Rick Fisher
	25	Picnic in Green Bank	
	27	Radio Telescope Theory	Jim Ulvestad
	29	Radiation Mechanisms in Astrophysics	Bob Brown
July	06	Interferometers	Larry D'Addario
	08	Supernovae	Steve Reynolds
	11	The VLA	Alan Bridle
	13	Gas in Galaxies	Martha Haynes
	15	The VLB Array	Craig Walker
	18	Polarization	Dan Stinebring
	20	Extragalactic Radio Sources	Alan Bridle
	22	Molecular Clouds	Al Wootten
	25	The Galaxy	Harvey Liszt
	27	Radio Stars and HII Regions	Dave Hogg
	29	The Chemistry of Interstellar Molecules	Barry Turner
Aug.	01	Pulsars	Dan Stinebring
	03	Dynamics of Galaxies	Dave Merritt
	05	Radio Emission from Spiral Galaxies	Jim Condon
	08	Superluminal Radio Sources	John Benson
	15	Summer Student Symposium	